U.S. ARMY
MATERIEL COMMAND

— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

NIZATION NAME(S) AND ADDRESS(ES) | 8.

INC.

ITORING AGENCY NAME(S) AND ADDRESS(ES) | 10

RSENAL (CO.). PMRMA
CO

19950329 079

EBASCO SERVICES INCORPORATED

R. L. Stollar and Associates
California Analytical Laboratories, Inc.
DataChem, Inc. Geraghty & Miller, Inc.

REQUESTS FOR COPIES OF THIS DOCUMENT
SHOULD BE REFERRED TO THE PROGRAM MANAGER
FOR THE ROCKY MOUNTAIN ARSENAL CONTAMINATION CLEANUP,
AMXRM ABERDEEN PROVING GROUND, MARYLAND

RMA 880193-¼

ROCKY MOUNTAIN ARSENAL • COMMERCE CITY, COLORADO • 80022-2180

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 09/00/88	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
SUMMARY REPORT FOR INCINERATION OF BASIN F WASTES AT ROCKY MOUNTAIN ARSENAL, TASK 17, FINAL

5. FUNDING NUMBERS
DAAK11 84 D 0017

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

EBASCO SERVICES, INC.
LAKEWOOD, CO

8. PERFORMING ORGANIZATION REPORT NUMBER

88286R01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

ROCKY MOUNTAIN ARSENAL (CO.). PMRMA
COMMERCE CITY, CO

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

THIS SUMMARY REPORT IS VOLUME 1 IN A SIX-VOLUME SET OF TECHNICAL REPORTS THAT SUMMARIZE THE RESULTS OF THE TASK 17 INVESTIGATIONS. VOLUME 2: FINAL SELECTION OF INCINERATION TECHNOLOGY FOR BASIN F WASTES AT ROCKY MOUNTAIN ARSENAL. VOLUME 3: FINAL ANALYSIS OF PILOT PLANT ALTERNATIVES FOR THE INCINERATION OF BASIN F WASTES AT ROCKY MOUNTAIN ARSENAL. VOLUME 4: FINAL BENCH-SCALE LABORATORY INCINERATION OF BASIN F WASTES AT ROCKY MOUNTAIN ARSENAL. VOLUME 5: FINAL BENCH-SCALE LABORATORY INCINERATION OF SECTION 26 WASTES AT ROCKY MOUNTAIN ARSENAL. VOLUME 6: FINAL FULL-SCALE INCINERATION SYSTEM CONCEPTUAL DESIGN FOR BASIN F WASTES AT ROCKY MOUNTAIN ARSENAL. ALL THE VOLUMES ARE DATED SEPTEMBER 1988.

14. SUBJECT TERMS
ROTARY KILN, COST, WASTE CHARACTERISTICS, BENCH-SCALE TEST

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED			

FINAL

VOLUME 2

SELECTION OF INCINERATION TECHNOLOGY FOR

BASIN F WASTES AT

ROCKY MOUNTAIN ARSENAL

SEPTEMBER 1988

TASK NO. 17

CONTRACT NO DAAK11-84-D-0017

Accesion For

NTIS CRA&I	☑	
DTIC TAB	☐	
Unannounced	☐	
Justification		

A-1

THE VIEWS, OPINIONS, AND/OR FINDINGS CONTAINED IN THIS REPORT ARE THOSE OF THE AUTHOR(S) AND SHOULD NOT BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, POLICY, OR DECISION, UNLESS SO DESIGNATED BY OTHER DOCUMENTATION.

THE USE OF TRADE NAMES IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS. THIS REPORT MAY NOT BE CITED FOR PURPOSES OF ADVERTISEMENT.

1110D

TABLE OF CONTENTS

-i-

1110D   08/05/88

LIST OF TABLES

06/21/88

LISTS OF FIGURES

1.0 INTRODUCTION

This chapter presents a discussion on the purpose of this report; study constraints and assumptions, including the quantity of contaminated material, waste characteristics, geologic nature of the soils, and other factors; and the study approach.

1.1 PURPOSE OF REPORT

The purpose of this report is to review incineration (thermal oxidation) technologies applicable to Basin F wastes (solids and liquids), and to select a technology for further analyses. In so doing, this report:

o   Reviews the technical problems associated with the incineration of Basin F wastes;

o   Surveys technologies commercially available, as well as technologies under development, that could be used for hazardous waste incineration;

o   Explains the fundamentals of incineration to consider if thermal oxidation is to be applied successfully;

o   Develops technology selection methodology and selection criteria;

o   Reviews, in detail, the most applicable candidate technologies for handling Basin F wastes; and

o   Applies the criteria to the most applicable technologies as a means for making a technology selection.

1.2 STUDY CONSTRAINTS AND ASSUMPTIONS

Basin F contains significant quantities of hazardous chemicals in both lagoon liquids and solids. The contaminated soils include overburden or soil placed above the liner, and some soils below a 3/8-inch asphalt liner. A detailed characterization of the Basin F contaminants is presented in the report titled "Final Technical Plan," dated April 1987 (Ebasco 1987). This material is only summarized here.

1.2.1 Quantity of Contaminated Material

The contaminants in the soils are largely residues from the manufacture of herbicides and nerve gas and include such compounds as aldrin, endrin, isodrin, dieldrin, dimethylmethylphosphonate (DMMP), diisopropylmethylphosphonate (DIMP), and other hydrocarbons and halocarbons. Toxicological data indicate that these compounds are extremely hazardous.

The quantities of contaminated materials associated with Basin F are shown below (Ebasco 1987):

Raw Waste Material	Quantity (cu. yd.)
Liquid (4 million gallons)	20,000
Overburden and Liner	240,000
Underlying Soils	146,000
Sewer Debris and Soils	12,000
TOTAL	418,000

Clearly, the overwhelming problem is in the incineration of soils, since the liquid waste accounts for only 4.8 percent of the total volume of waste at Basin F. Overburden and liner are 57 percent of the volume of material

to be processed, given the estimates presented above. It is impossible to determine the percentage of hazardous compounds present in the material with any precision, due to wide variations in concentrations of hazardous compounds.

1.2.2 Waste Characteristics

The dimensions of the problem are best estimated from a bulk materials perspective. However, applicability of incineration to the problem requires analysis of the hazardous waste contaminants themselves, necessitating consideration of the hazardous organic compounds in the Basin F wastes from a thermal treatment perspective. Properties of importance include empirical formula, molecular weight, melting point, boiling point, flash point, autoignition temperature, and calorific content. The identified physical, chemical, and thermodynamic properties of compounds found in Basin F liquids and soils are shown in Table 1.2-1. In addition to organic compounds, the liquids in Basin F contain chloride and sulfate ions, metals, and other contaminants. Chemical characterization of Basin F liquids is shown in Table 1.2-2. Concentration levels of contaminants from a representative soil boring are shown in Table 1.2-3.

Given the concentrations shown in Tables 1.2-2 and 1.2-3, it is apparent that the materials have extremely dilute concentrations of hazardous wastes. Neither the soils nor the liquid are capable of sustaining combustion, although the asphalt liner has significant calorific value and is combustible. The problem, then, is not one of incineration of a burnable hydrocarbon solvent or halocarbon solvent, but rather, the problem is one of soils cleaning to reduce the hazardous nature of the contaminated soils, as well as the thermal treatment of a contaminated liquid that has no calorific content.

1.2.3 Geologic Nature of Soils

The concentration of contaminants is one characteristic of soils necessary to determine their suitability for treatment by incineration. Another consideration is the geologic nature of the soils themselves. The entire

TABLE 1.2-1

PROXIMATE AND ULTIMATE ANALYSIS, HIGHER HEATING VALUE,
ASH FUSION TEMPERATURE, REACTIVITY, AND CORROSIVITY
OF BASIN F LIQUIDS AND OVERBURDEN[1]

Parameter	Liquid	Overburden
Proximate Analysis (wt percent, wet)		
Moisture	N/A [2]	23.95
Volatiles	N/A	14.48
Fixed Carbon	N/A	2.33
Ash	N/A	59.24
		100.00
Ultimate (Short form, wt percent, wet)		
Carbon	8.21	9.07
Hydrogen	9.23	4.12
Nitrogen	8.79	0.78
Higher Heating Value (Btu/lb)		
Wet basis	4	37
Ash Fusion Temp. (°C)[3]		
Initial Deformation	N/A	1228-1234
Softening	N/A	1276-1303
Hemispheric Lump	N/A	1378-1439
Fluid	N/A	1529-1649
Reactivity (mg/gm)		
Cyanide	<0.02	3.6
Sulfide	<0.02	<0.02
Corrosivity (mm/yr)[4]	50	1.1

[1] Tests were conducted by UBTL in Salt Lake City.
[2] Not available.
[3] On one ash fusion analysis, an eutectic effect was indicated.
[4] EPA Method 1110.

TABLE 1.2-2

CHEMICAL CHARACTERIZATION OF BASIN F LIQUID (ppm)

Compound or Parameter	Concentration[1][3]/ 1986 Data	Concentration[2][3]/ 1977 Data
pH	N/A[4]/	6.9 - 7.2
Aldrin	2.3	50 - 400
Isodrin	2.0	0.002 - 0.015
Dieldrin	0.5	0.005 - 0.110
Endrin	0.6	0.005 - 0.040
Dithiane	N/A	0.03 - 0.100
DIMP	0.4	10 - 20
DMMP	N/A	500 - 2,000
Sulfoxide	1	4 - 10
Sulfone	1	25 - 60
Chloride	120,000	48,000 - 56,000
Sulfate	N/A	21,000 - 25,000
Copper	N/A	700 - 750
Iron	N/A	5 - 6
Nitrogen	N/A	120 - 145
Phosphorus (total)	N/A	2,050 - 2,150
Hardness	N/A	2,100 - 2,800
Fluoride	21	110 - 117
Arsenic	N/A	1 - 1.3
Magnesium	N/A	35 - 40
Mercury	0.2	0.026 - 0.029
Cyanide	N/A	1.45 - 1.55
COD	N/A	24,500 - 26,000
TOC	N/A	20,500 - 22,500

1/ New analytical data are from recent Basin F sampling efforts under this program.

2/ Based on the analysis of various samples from different locations and depths in the basin (Buhts et al. 1979).

3/ Values in percent are calculated by dividing the ppm table values by a factor of 10,000.

4/ Not available.

TABLE 1.2-3

ANALYTICAL RESULTS FROM SOLID WASTE
LEACHATE PROCEDURES (SWLP) CONDUCTED ON SAMPLES (ppm)[1]

Analyte	Core Subsample Identification				
	0.0-1.0 ft	1.0-2.0 ft	2.0-3.0 ft	3.0-4.0 ft	Overburden
pH	6.5	8.2	8.2	8.7	7.2
Aldrin	0.30	0.61	0.71	0.40	5.07
Dieldrin	0.22	0.013	2.41	0.54	19.5
Endrin	0.40	0.20	2.22	0.91	24.4
Isodrin	0.11	0.005	0.005	0.11	0.41
DIMP	70	90	110	110	30
DMMP	BDL[2]	BDL	BDL	BDL	BDL
Dithiane	BDL	BDL	BDL	BDL	BDL
Sulfone	BDL	BDL	BDL	BDL	BDL
Sulfoxide	BDL	BDL	BDL	BDL	BDL
Dibromochloro-phosphonate	BDL	BDL	BDL	BDL	0.010
Mercury	BDL	BDL	0.12	0.12	0.22
Arsenic	95	110	110	90	110
Fluoride	7.0	9.5	12.3	15.2	3.3

1/ All values other than pH are reported as ppm unless otherwise noted.

2/ Below detection limits.

Rocky Mountain Arsenal (RMA) site is covered with alluvial soils, except in areas where alluvial deposits were removed and the Denver Formation was exposed. The alluvium of RMA consists of clays, silts, sands, gravel, and boulders and is generally unconsolidated. The Denver Formation, in which Basin F is located, consists of clay shale and compact sand (Ebasco 1985). Consequently, the contaminated soils are expected to include significant quantities of sand. Further, the contaminated soils under the liner may include mixtures of sand, gravel, and clay.

A particle size distribution of Basin F solids is presented in Figure 1.2-1. It can be seen that the particle size extends two orders of magnitude, from medium sand to silt or clay. The figure indicates that 50 percent of the material is greater than 80 mesh. Over 25 percent is less than 100 microns and 5 percent is less than 10 microns.

The bulk density was experimentally determined to be 130 lb/ft^3 wet and 100 lb/ft^3 dry. The specific heat of the soil was estimated at 0.2 to 0.25 Btu/lb °F for the dry material (Perry and Chilton 1984).

Additionally, the presence of clay, to varying extents, provides "growth" properties to the soils since clays expand following excavation and when either wetted or heated.

The incineration system (or some component thereof) must be capable of evaporating the water in the Basin F liquid and destroying the remaining contaminants. One dominant problem in the treatment of such liquids is their associated salt content. Salts can attach to the refractory material in incinerators, and high salt contents must be accommodated in the design.

1.2.4 Other Factors

It is also important to consider the incinerator in terms of the technical requirement for destruction and removal of organics. The system used to process the contaminated soils and liquids at Basin F is to achieve a
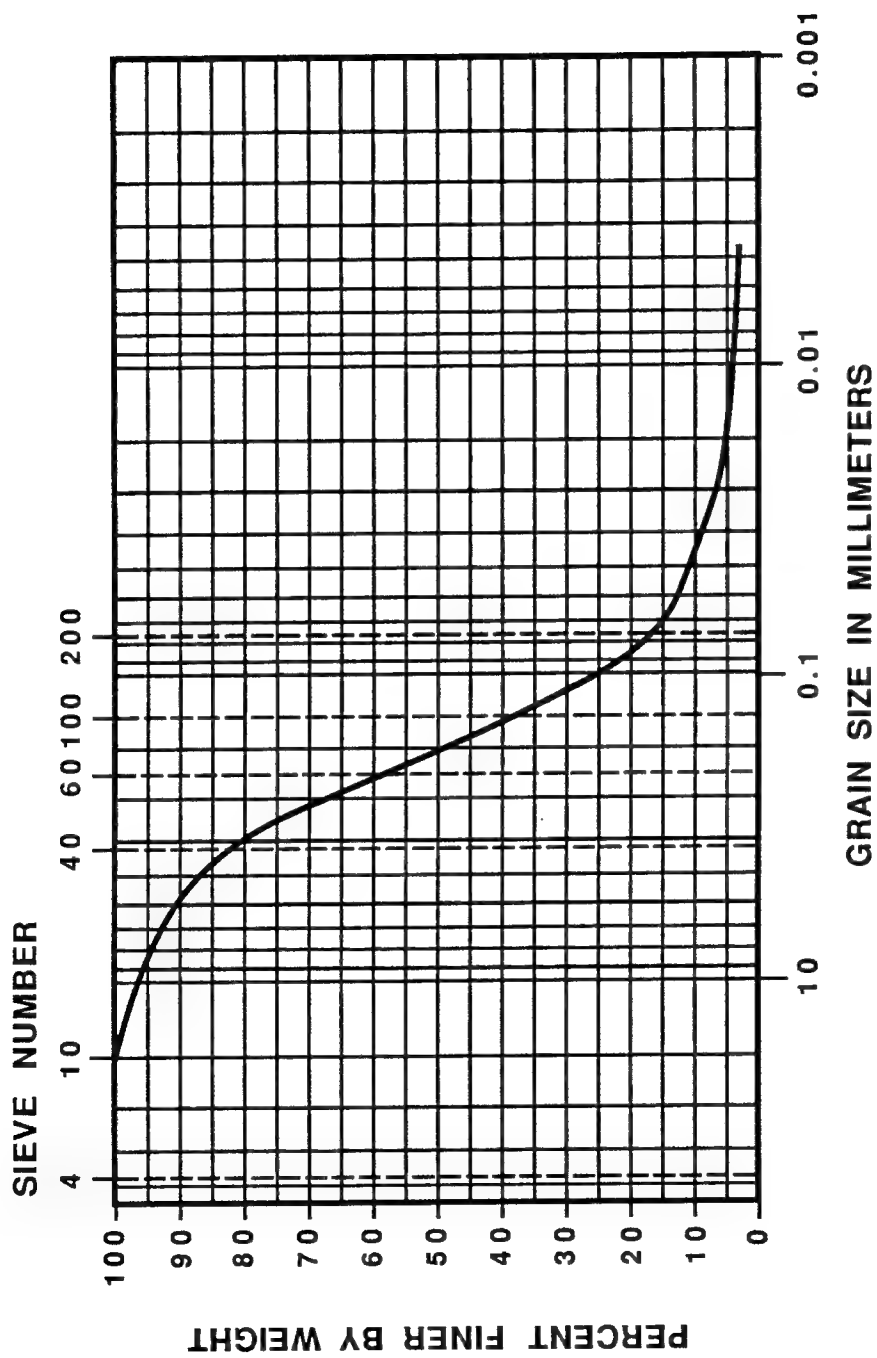
FIGURE 1.2-1

PARTICLE SIZE DISTRIBUTION OF BASIN F SOLIDS

MDMS6133

destruction and removal efficiency (DRE) of 99.99 percent for principal organic hazardous constituents (POHCs). The DRE of 99.99 percent should be achieved while minimizing products of incomplete combustion (PICs). Finally, it is important to consider the time frame available to achieve incineration treatment of the Basin F wastes. The incineration program, and the technology selected, must be capable of treating the contaminated soils and liquids in a 2.5-year time frame at 80 percent availability as determined by the Program Manager's Office (PMO).

1.3 STUDY APPROACH

The purpose of this report is to document the selection of the most appropriate system for incinerating the contaminated soils, sludges, liner materials, and liquids that are located in Basin F at the Rocky Mountain Arsenal. To this end, this report:

o   Provides a discussion of the fundamentals of incineration (thermal oxidation) and reviews hazardous waste incineration technologies;

o   Establishes a methodology for selecting an incineration technology;

o   Provides detailed discussions of the technologies available; and

o   Documents the application of that methodology in the selection of the most effective incineration system.

2.0 INCINERATION TECHNOLOGY OVERVIEW

A wide variety of incineration or thermal oxidation/destruction technologies exist that are capable of achieving 99.99 percent destruction and removal efficiency of the contaminated soils and other hazardous wastes in Basin F at Rocky Mountain Arsenal. These technologies include the following (Freeman et al. 1985):

- o   Rotary kiln combustors;
- o   Fluidized bed combustors;
- o   Hearth-type combustors;
- o   Pyrolysis systems;
- o   Plasma torch reactors;
- o   Molten salt combustors;
- o   Molten glass reactors;
- o   Electric furnace-type reactors;
- o   Chemical transformation systems;
- o   Wet oxidation systems; and
- o   Liquid injection systems.

All of these technologies, except wet oxidation and liquid injection systems, are used for handling solids as well as liquids. All of these technologies are commercially available or under development. However, it should be noted that only the rotary kiln and fluidized bed incinerators have been used to thermally treat large volumes of soil.

Of these 11 technologies, 4 represent over 99.5 percent of all domestic units manufactured. They are liquid injection, hearth, rotary kiln, and fluidized bed, accounting for 64.0, 20.6, 12.3, and 2.6 percent, respectively. A review of all 11 technologies follows. This review establishes the operating characteristics, applicable wastes, destruction and removal efficiency, and commercial availability of each technology. The following general references include this information: Kiang and Metry (1982), Keitz et al. (1984), Edwards et al. (1983), Freeman et al. (1985), Bonner et al. (1981), and Brunner (1984).

1176D

08/05/88

2.1 ROTARY KILN

A rotary kiln incinerator is a refractory-lined cylindrical shell mounted at a slight incline to the horizontal plane. The kiln length and speed of rotation are used to control waste residence time and mixing with combustion air. Typical solids residence times range from 20 minutes to 2 hours. Most of the heating of the wastes is due to heat transfer from the combustion gases and kiln walls. Fuel sources generally include natural gas, oil, or pulverized coal. There are two types of kilns currently being manufactured in the United States--cocurrent (burner at the same end as the waste feed) and countercurrent (burner at the back end or kiln discharge). Kilns generally have a length-to-diameter ratio of 2 to 15 and a rotational speed of 1 to 5 ft per minute at the periphery. Detailed combustion regime parameters depend upon the waste being fed as discussed in Chapter 3.0. Afterburners are usually employed with rotary kilns to assure complete oxidation of the contaminants in the flue gases prior to their entry into air pollution control equipment and subsequent discharge to the environment.

Rotary kilns are used at regional incineration facilities as well as at Superfund sites. They incinerate a wide range of materials including solvents, polyvinyl chloride wastes, obsolete munitions, polychlorinated biphenols (PCBs), herbicides, pesticides, and obsolete chemical warfare agents, to mention a few. As of 1984, there were 17 domestic companies manufacturing rotary kilns, 37 units in service incinerating hazardous waste, and 5 kilns under construction. Rotary kilns represent 12.3 percent of the hazardous waste incinerators in the United States. Mobile rotary kiln incinerators are available from Environmental Services Corporation (ENSCO), IT Corporation, Roy Weston, Vesta, Rollins, and others.

Systems under development include the Consertherm Rotary Kiln Oxidizer by Industronics, Inc., which is modular in design, and the Fast Rotary Reactor Incinerator by PEDCo Technology Corporation, which rotates at 8 to 20 rpm providing high heat transfer by maximizing contact between the solids and gases.

2.2 FLUIDIZED BED

A fluidized bed combustor is a refractory-lined vertical vessel containing a bed of inert granular material (e.g., sand). Combustion air (fluidizing air) is introduced via a plenum under the bed, and rises vertically while fluidizing the sand bed. Hazardous waste materials and fuel (if required) are introduced directly into the bed. The bed transfers heat to the waste material, and, in turn, the waste and auxiliary fuel return heat to the bed during combustion. If the waste contains inorganic materials, the bed is gradually replaced with the inorganic material generated by incineration. In this situation, continuous bed removal of inerts is required. Bed depths are usually 3 ft at rest and 6 ft when operating. Variations in bed depth directly affect pressure drop and residence time. A compromise is required in bed depth to maximize the residence time and minimize incomplete combustion. The bed temperature is limited by the softening point of the bed material, typically 900°C for sand. Salts such as sodium chloride form eutectic mixtures that can limit bed temperatures to approximately 650°C.

Most applications of fluidized bed technologies are incineration of sludges and slurries. Fluctuation in feed rate and composition can be easily tolerated due to the large thermal mass stored in the bed. This bed also provides for the rapid drying of high moisture content materials. The fluidized bed handles most of the wastes that the rotary kiln is capable of handling, although temperature limitations exist due to the softening point of the bed. It is not capable of handling bulky residue like the rotary kiln, without size reduction of the feed material.

As of 1984, there were nine domestic manufacturers of fluidized bed incinerators and nine incinerators in hazardous waste service. This represents 2.6 percent of the hazardous waste incinerators in service in the United States. Technologies under development include the Multisolid Circulating Fluidized Bed by Battelle, with a decoupled heat exchanger and retention time of 10 seconds to several minutes at 540-1,110°C, and the Low Temperature Fluidized Bed Incinerator by Waste-Tech Services, Inc., using a bed of granular combustion catalyst and limestone operating at 760-925°C. A

mobile circulating fluidized bed incinerator is available from Ogden
Environmental Services. Fluidized bed technology is discussed in more
detail in Chapter 4.0.

2.3 HEARTH TYPE

There are several types of hearth furnaces including fixed hearths, and
single and multiple rotating hearths. Fixed hearths are mostly used for the
combustion of fuels that have a substantial heating value, including wood,
agricultural, and food processing residues; coal and hospital wastes; and
municipal solid waste. These configurations are discussed in detail in
Chapter 4.0. However, for Basin F material, the multiple hearth is most
useful and is therefore reviewed here.

The multiple hearth incinerator, such as the Herreshoff Furnace, is used
especially for sewage sludge burning. A typical multiple hearth furnace
includes a refractory-lined steel shell, a central shaft that rotates, a
series of solid flat hearths, a series of rabble arms with teeth for each
hearth, an air blower, fuel burners mounted on the walls, an ash removal
system, and a feed system. Sludge or granular solid materials enter the
furnace and are distributed on the top hearth by the air-cooled rabble arms
and teeth. The waste falls from the top hearth to the next hearth and
subsequent hearths until the waste reaches the bottom hearth, where it is
discharged as ash. The teeth in each hearth agitate the sludge, exposing
new surfaces of the sludge to the gas flow. Waste retention time is
controlled by the tooth pattern on the arms, rotational speed of the central
shaft, and the number of hearths. A typical furnace generally has from five
to nine hearths. Normal incineration usually requires a minimum of
six hearths, while pyrolysis requires a greater number. Liquid and gaseous
wastes are injected into the furnace by side wall-mounted nozzles. A
multiple hearth generally has three distinct zones--the upper zone, which
dries the waste and operates at 350-550°C; the second zone, which
incinerates the waste and operates at 800-1,000°C; and the last zone, which
cools the material (ash) and operates at 200-350°C. Temperatures on each
hearth are maintained by supplemental fuel firing. Generally, the upper
hearth acts as the afterburner.

1176D

06/21/88

Multiple hearths are best suited for sludge containing hazardous waste. As with the fluidized bed, waste to be burned is usually pretreated to reduce particle size, making the waste relatively homogeneous. Material not suited for multiple hearths includes wastes with a high salt content.

As of 1984, there were 16 domestic manufacturers of hearth-type incinerators and 70 installations in the United States. This represents 20.6 percent of the number of hazardous waste incinerators in the United States.

2.4 PYROLYSIS REACTORS

Pyrolysis, in the true sense of the word, is the thermal decomposition of a normally carbonaceous material in the absence of oxygen; not to be confused with starved air combustion, which is the thermal decomposition of a material with substoichiometric amounts of oxygen. Pyrolytic conversion units are usually custom engineered according to the input volumes and characteristics of the waste requiring disposal. The off-gases, once cooled, are separated into a variety of components, including acetic acid, methanol, furfural, acetone, butyric acid, proprionic acid, methyl ethyl ketone, light fuel oils, and other water soluble organics. The charlike pyrolysis residue is converted into activated carbon. The pyrolyzer itself may be a rotary kiln, multiple hearth furnace, or other combustion technology where air can be omitted. Heat to the material undergoing the pyrolysis reactions is generally supplied by burning the following: off-gases in an afterburner, a supplemental fuel, or a portion of the waste itself. Operating temperatures are typically around 500-800°C, with residence times ranging from a fraction of a second for flash pyrolysis to several hours for solids. The major disadvantage of pyrolysis is that the system tends to form carcinogenic decomposition products and does not operate very well on materials that cake or fuse.

Materials that contain carbon, hydrogen, and/or oxygen can be pyrolyzed. If by-product recovery is not desirable, the by-product materials are burned or disposed of in an environmentally safe manner.

Systems being developed for the pyrolysis of hazardous waste are the continuous and batch Pyrotherm processes, the High Temperature Pyrolysis with Oxygen System, and the Electric Pyrolyzer by Westinghouse. The Pyrotherm process is a continuous or batch system. In the Pyrotherm process, waste is batch or continuously fed into an indirect-fired, oxygen-free, pyrolytic chamber operating at 540-870°C for a 15 to 30 minute reaction time. The gas is combusted in a fume reactor and goes to a heat recovery system. The Pyrotherm system is permitted at McDonnel Douglas Company in St. Charles, Missouri, and treats wastes in 55-gallon drums. The High Temperature Pyrolysis system closely resembles that of a blast furnace with environmental controls and processing for heat recovery. The system operates at 800-1,650°C, with a residence time of 15 to 30 minutes. The Westinghouse Electric Pyrolyzer is a refractory-lined pyrolytic furnace that operates at 1,650°C. This system consists of a molten phase generated by an electric arc. The system is designed to handle solids. A 90-140 ton/day unit is planned (Westinghouse 1987).

2.5 PLASMA TORCH INCINERATORS

The plasma torch is a device that utilizes an electrical discharge to change almost any gas into a plasma, the hottest sustainable flame known, at up to 55,000°C. A plasma is considered a fourth state of matter and is composed of equal amounts of positively and negatively charged particles, so that in bulk it is electrically neutral. Three plasma systems are currently under development: Pyroplasma system by Pyrolysis Systems Incorporated, the Plasma Temperature Incinerator by Applied Energetics, and the Pyroplasma system of Westinghouse.

In the Pyroplasma system, a plasma is formed with a near zero charge and an electron temperature of 28,000°C. As the activated components of the plasma decay, their energy is transferred to the waste material, ultimately destroying the waste. The system is capable of handling highly toxic materials with a typical residence time of 1 second. Destruction efficiencies of up to 99.9999 percent have been obtained with PCBs in a unit developed at the Royal Military College in Langston, Ontario, which handles

up to 500 pounds of sludge per hour (or 6 tons/day). The unit is portable, but is not yet commercially available.

The system by Applied Energetics uses clean fuel to preheat oxygen to 1,000°C. The preheated oxygen enters the combustion chamber and autoignites almost any fuel. The combustion reaction rates have been shown to increase by tenfold, with the waste being completely consumed in 35-50 milliseconds. Construction and testing of a commercial-sized unit has not yet begun.

The Westinghouse Pyroplasma system operates at temperatures around 10,000-20,000°C. This system consists of a plasma torch coupled to a high temperature reaction chamber, followed by a caustic water scrubber, separator, and induced draft fan. The system is designed to handle liquid organic wastes, which pass a 0.016-inch screen. One small unit has been sold to the state of New York, with another unit undergoing field testing. Westinghouse is still developing the system interfacing, including pumps and other mechanical equipment (Westinghouse 1987).

2.6 MOLTEN SALT INCINERATORS

The molten salt process was developed by Atomics International, a division of Rockwell International Corporation. The system is not a true incinerator because no flame is produced. However, it is an oxidation process where wastes are oxidized and/or chemically altered to innocuous substances. The salt, usually sodium carbonate, is heated (between 800 and 1,000°C) until it is molten. Solid waste is shredded before feeding into the salt bed, while liquid or sludge wastes are injected directly. Exhaust gases include carbon dioxide, water (steam), nitrogen, oxygen, and particulate. The spent melt is disposed of directly or reprocessed by separating out the ash and recycling the salt. Supplemental fuels are used as required to maintain the temperature of the salt.

In the Rockwell process, the waste and air (or oxygen-enriched air) are injected under the surface of the molten salt pool. The phosphorus, sulfur,

arsenic, and halogens react with the salt and remain in the bed rather than being released to the atmosphere. When the ash content exceeds 20 percent in the bed, the melt is continuously or batch removed for separation and addition of more salt. The system is most effective for low moisture, low ash, solid and liquid wastes. Residence time is approximately 5 seconds at 800-1,000°C. Pilot-scale units treating up to 250 lb/hr of waste have been developed. Rockwell is looking for licensees to demonstrate and commercialize the process. The technology has been tested using explosives, propellants, chemical warfare agents, pesticides, herbicides, hazardous organic liquids, and hazardous solids.

2.7 MOLTEN GLASS REACTORS

This process uses a pool of molten glass as the heat transfer mechanism to destroy organics. The combustion conditions for organics appear to be at least as good as those present in hazardous waste incinerators, and the inorganic residue and ash is incorporated into the glass. It has been indicated that the residue is nonleachable. Ceramic fiber filters are used to remove particulate matter and, as they become contaminated, are pushed into the melt and dissolved into the glass.

Systems under development include the Joule-Heated Glass Melter by Battelle Northwest and the Electromelt Pyro-Converter by Penberthy Electromelt International.

The Battelle process uses joule heating (resistance heating) by utilizing the material as a resistance element in an electrical circuit. It is thought that the system would be highly adaptable to the destruction and fixation of industrial contaminated soils or other granular material. The process would accept soils directly. Typical operating temperatures are around 1,200°C. The system is not yet commercial.

The Electromelt Pyro-Converter is a tunnel incinerator that has a pool of molten glass covering the bottom. Bulky wastes are introduced via a door in one end, while dirt and liquid or slurry wastes are introduced by a screw

conveyor or pipe, respectively. Materials oxidize with air in the first half of the combustion chamber. Dirt and noncombustibles drop onto the glass pool and into the melt. The entire molten glass pool is kept above 1,200°C. The particulates in flue gases can be collected by a set of ceramic filters that, when loaded, are dissolved into the glass melt. The stack gases pass through two spray chambers (where hydrochloric acid is converted to sodium chloride) and a charcoal filter before being exhausted. The filter sludge from the spray chamber and the charcoal are dissolved in the melt. The system will handle such wastes as rubber, plastic, PCBs, toluene, oil, dirt, and metals. The Pyro-Converter is sold as chemical processing equipment. A typical furnace capacity is 1 to 25 tons/day.

2.8 ELECTRIC FURNACE REACTORS

The electric reactor pyrolyzes waste contaminants off particles of soil through the use of an electrically heated fluid wall reactor. Technology development is being conducted on the High-Temperature Fluid Wall Reactor (HTFR) by Thugard Research Corporation and the Advanced Electric Reactor by the J.M. Huber Company.

The HTFR is basically a hot column, heated by electric resistance heaters, through which finely divided material is dropped, undergoing pyrolytic decomposition and chemical reaction during its fall through the hot zone. The reactor operates at temperatures of about 2,200°C. Heat transfer is dominated by radiation and is thus very rapid. A porous inner wall purged with nitrogen is used to prevent fouling of the wall. Residence time is approximately 0.1 to 1.0 seconds. Electrical requirements are 400 kW per ton of feed material. Destruction efficiencies as high as 99.999 percent have been achieved.

The Advanced Electric Reactor process of J.M. Huber Company employs intense thermal radiation in the near-infrared region to rapidly heat materials to about 2,200°C. Residence time ranges from 5 to 10 seconds. Again, a porous wall with a nitrogen blanket is used to protect the unit's walls.

Destruction is accomplished by pyrolysis rather than oxidation. Solid, liquid, and gaseous wastes can be handled. The technology also has demonstrated, in the laboratory, the ability to handle soils on a continuous basis as well as pure PCBs, heavily halogenated hydrocarbons, dioxins, and nerve gas. For contaminated soils, the system requires approximately 800-1,000 kWh/ton. Destruction efficiencies have exceeded 99.9999 percent on carbon tetrachloride.

2.9 CHEMICAL TRANSFORMATION SYSTEMS

Chemical transformation systems transform the waste material into other, less toxic, substances primarily through chemical reaction. These technologies encourage resource recovery rather than destruction of the wastes. Two technologies are reviewed here: Aqueous Phase Alkaline Destruction of Halogenated Organic Wastes by Battelle Northwest and Catalytic Dehalogenation by the GARD Division of Chamberlain Manufacturing Company.

In the Battelle Northwest process, organic matter is digested with mild alkali under pressure, and in the absence of oxygen. The result is the conversion of organic solids into an oil. Feed material includes halogenated liquids and granular solids. The process produces its own thermal energy from the sensible heat of the reacting materials. Operating conditions include a residence time of 0.5-5 hours, a temperature range of 250-400°C, and a pressure of 430-2,900 psig. Destruction ranges from 99 percent for lindane to less than 10 percent for 2,4,5-T. The process is still in the laboratory stage with research needed on vulnerability of chemical attack and the determination of the toxicity of the products produced.

The GARD process treats halogenated compounds by replacing the halogen atoms with a hydrogen atom. Relatively mild conditions result in uncomplicated equipment. The method is only applicable for liquid halogenated solvents.

Both processes above have been tested in the laboratory. Pilot plant facilities would be the next step in their development.

2.10 LIQUID INJECTION INCINERATORS

Liquid injection incinerators are only mentioned here since they are more thoroughly evaluated in the report titled "Full-Scale Incineration Conceptual Design for Basin F Wastes" (Ebasco 1988). Liquid injection is the most commonly used incinerator technology for the disposal of hazardous waste materials. These units are typically gas and oil fired burners. These incinerators only combust liquids, slurries, and sludges. This limitation exists since the droplet must be converted to the gas phase prior to combustion. Typical combustion chamber residence time and temperature ranges are 0.5-2 seconds and 700-1,650°C, respectively. The combustion zone is refractory lined, with the burner positioned so flames do not impinge directly on the refractory walls. The units are either horizontally, vertically, or tangentially fired. The tangential units have superior heat release and better mixing than the other types. Supplemental heat is required if the heat content of the material is not capable of sustaining combustion. Only wastes capable of atomization are incinerable. Liquid incinerators are commercially available and represent 64 percent of the incinerators currently in use in the United States.

2.11 WET OXIDATION

Wet oxidation is a process for oxidizing suspended and dissolved organics in aqueous waste streams. This process is very effective at detoxifying aqueous waste streams that are too dilute to incinerate economically, yet too toxic to treat biologically. Wet oxidation does not work very well on chlorinated organics. However, it is a promising technology for aqueous waste containing nonchlorinated toxic organics. Wet oxidation systems are being developed by ZIMPRO Incorporated, IT Corporation, Modar Inc., and Methods Engineering Incorporated. The ZIMPRO unit is commercially available, while the other systems are not yet available.

2.12 CONCLUSION

Rotary kilns, fluidized beds, and hearth-type furnaces are the only reactors that have been commercially constructed, operated, and, therefore, proven to be capable of "incinerating" solids. As a result, these technologies are carried forward for more detailed evaluation. Liquid injection incineration is evaluated in the Full-Scale Conceptual Design Report (Ebasco 1988) for Basin F liquids.

Pyrolysis, plasma torch, molten salt, and molten glass all have the capability of handling solids. However, these technologies have not been constructed, operated, proven commercially, or they are scale limited.

3.0 INCINERATION TECHNOLOGY SELECTION CRITERIA

Development of proper incineration technology selection criteria involves application of combustion fundamentals to the specific program at hand. The application of the fundamentals of combustion to Basin F wastes is discussed in Appendix A. These fundamentals are discussed and applied to the development of selection criteria.

3.1 INTRODUCTION

Hazardous compounds (organics) burn in the gas phase. Initially, Basin F soils or soils mixed with Basin F liquids must be heated to temperatures sufficiently high to volatilize organic contaminants. Once completely heated to temperatures in the 500-1,000°C range, chemical contaminants in the soils enter the gas phase either by boiling, sublimation, or pyrolysis. For generating selection criteria, a conservative temperature of ≥ 900°C is necessary in the primary chamber to ensure virtually complete volatilization of the contaminants in the Basin F material. Additional discussion of rationale for selection criteria is in Appendix A. As discussed in the Appendix, the destruction of organic contaminants will occur in the gas phase in the presence of oxygen.

The work of Dellinger et al. (1984) concerning thermal decomposition behavior of various organic compounds, as shown in Table 3.1-1, provides guidance for temperature selection.

Given the data in Appendix A, the incineration regime necessary for technology selection is summarized below:

o   It is assumed that the primary reactor temperature must exceed 900°C in any primary burner and 1,000°C overall. A 950°C temperature is required for 99.99 percent DRE within a 2-second residence time for acetonitrile, which is the most thermally stable compound found by Dellinger et al. (1984). Organic contaminants,

TABLE 3.1-1

SUMMARY OF THERMAL DECOMPOSITION DATA
FOR A 2-SECOND GAS RESIDENCE TIME

Compound	Empirical Formula	T_{onset} [1] (°C)	T_{99} [2] (°C)	$T_{99.99}$ [3] (°C)
Acetonitrile	C_2H_3N	760	900	950
Tetrachloroethylene	C_2Cl_4	660	850	920
Acrylonitrile	C_3H_3N	650	830	860
Methane	CH_4	660	830	870
Hexachlorobenzene	C_6Cl_6	650	820	880
1,2,3,4-Tetra- chlorobenzene	$C_6H_2Cl_4$	660	800	850
Pyridine	C_5H_5N	620	770	840
Dichloromethane	CH_2Cl_2	650	770	780
Carbon Tetrachloride	CCl_4	600	750	820
Hexachlorobutadiene	C_4Cl_5	620	750	780
1,2,4-Trichlorobenzene	$C_6H_3Cl_3$	640	750	790
1,2-Dichlorobenzene	$C_6H_4Cl_2$	630	740	780
Ethane	C_2H_6	500	735	785
Benzene	C_6H_6	630	730	760
Aniline	C_6H_7N	620	730	750
Monochlorobenzene	C_6H_5Cl	540	710	780
Nitrobenzene	$C_6H_5NO_2$	570	670	700
Hexachlorethane	C_2Cl_6	470	600	640
Chloroform	$CHCl_3$	410	590	620
1,1,1-Trichloroethane	$C_2H_3Cl_3$	390	570	600

Source: Dellinger et al. 1984.

[1] The temperature at which thermal decomposition begins with a residence time of 2 seconds.

[2] The temperature at which 99 percent of the compound is thermally decomposed with a residence time of 2 seconds.

[3] The temperature at which 99.99 percent of the compound is thermally decomposed with a residence time of 2 seconds.

such as aldrin, endrin, dieldrin, and isodrin, which are present in Basin F waste, have higher heat of combustion values than tetrachloroethene, the second most thermally stable compound in Table 3.1-1 (Appendix VIII, 40 CFR 261). The temperature required for 99.99 percent DRE of hexachlorobenzene is 880°C. Therefore, preliminary selection of a 900-1,000°C operating temperature for the destruction of organics associated within Basin F is appropriate. A conservative regime for afterburner operation will exceed 1,000°C.

o Since all hazardous compounds burn in the gas phase, an afterburner is necessary regardless of the type of primary incinerator employed. The afterburner could be a large freeboard space in a fluidized bed, capable of having a residence time of 2 seconds. Any system without an afterburner of some type has a significantly lower probability of success.

o Of the interrelated factors (3Ts--time, temperature, and turbulence) of combustion, temperature is probably the most critical. Time is of less importance in achieving 99.99 percent DRE. Turbulence is ensured by combustion system design. Because temperature is probably most critical, the preferred reactor must be capable of achieving high temperatures, both in the primary incinerator and in the afterburner. Further, the primary incinerator must have highly desirable heat transfer characteristics from the heat source (e.g., fossil fuel flame) to the contaminated soils. Without highly effective heat transfer mechanisms, the high temperatures achieved will be less than optimally employed.

3.2 IDENTIFICATION OF SCREENING CRITERIA

Given the problems associated with incinerating contaminated soils and liquids at Basin F and the range of technologies potentially available to treat Basin F wastes (rotary kiln, fluidized bed, and multiple hearth),

1177D   06/21/88

definitive technology selection criteria are essential. The Task 17
Technical Plan (Ebasco 1987) outlines the preliminary selection criteria
that are presented here in Table 3.2-1. This table lists the criteria that
are necessary to define the final design characteristics of any incinerator,
regardless of technology selected. However, some of these criteria are
inherently incapable of making a clear distinction between competing
technologies. Criteria where all technologies are equal are therefore
excluded from further consideration or incorporated into more global
considerations. Such criteria are listed below:

o Safety for off-site personnel;
o Environmental safety;
o Explosion potential;
o Proven operations;
o Turndown ratio;
o Atmosphere effluent treatment;
o Waste water effluent;
o Ash treatment;
o Equipment reliability;
o Sensitivity to pressure and temperature changes;
o External utility power required for startup;
o Air emission;
o System safety;
o Storage and mixing of waste;
o Startup/shutdown time and sequence;
o Water requirements;
o Water pollution;
o Biological effects;
o Noise;
o Heat exchanger maintenance;
o Corrosion problems anticipated;
o Need for specialized maintenance personnel; and
o Construction aspects.

TABLE 3.2-1

SELECTION CRITERIA OF INCINERATION TECHNOLOGY ALTERNATIVES

A. SAFETY ASPECTS

1. Operator safety
2. Safety for off-site personnel
3. Environmental safety
4. Explosive potential

B. DESIGN ASPECTS

1. Operating temperature
2. Residence time
3. Waste feed rate or capacity
4. Atmosphere effluent treatment
5. Waste water effluent
6. Ash treatment

C. OPERATIONAL ASPECTS

1. Proven operations
2. Equipment reliability
3. Sensitivity to feed composition
4. Sensitivity to feed consistency
   (i.e., viscosity or pumpability)
5. Sensitivity to pressure and
   temperature changes
6. Turndown ratio
7. Requirement for skilled operators
8. Storage and mixing of waste
9. Startup and shutdown time and
   sequence
10. External utility power required
    for startup
11. Fuel balance flexibility/heating
    valve (Btu/lb)
12. Water requirements
13. Air emissions
14. Systems safety

D. ENVIRONMENTAL ASPECTS

1. Air pollution
2. Water pollution
3. Biological effects
4. Noise

E. MAINTENANCE ASPECTS

1. Corrosion problems anticipated
2. Need for specialized
   maintenance personnel
3. Arduous service for valves,
   instruments, and seals
4. Heat exchanger maintenance
5. Rotating equipment maintenance
6. Refractory maintenance

F. COST ASPECTS

1. Capital cost
2. Operating cost

G. CONSTRUCTION ASPECTS

1. Special materials required in
   construction
2. Specialized construction
   personnel required
3. Large footprint (Layout Area)
4. Fabrication time
5. Erection time

The criteria ultimately used to distinguish between technologies are shown in Table 3.2-2. These criteria are discussed below.

3.3 DESIGN/OPERATION CRITERIA

The design and operation criteria represent the most critical elements that ultimately affect the selection of technologies. Failure to achieve specific conditions results in an inability to achieve a 99.99 percent DRE for the POHCs.

Reaction temperatures are the first critical parameter. As suggested by the Dellinger et al. (1984) data reported in Table 3.1-1, some of the organic components contained in the soils require combustion regime temperatures of 900-1,000°C to achieve 99.99 percent DRE. In the absence of more definitive data, it is assumed that the soil matrix and dilute concentration of contaminants raise that temperature requirement to over 1,000°C in order to ensure destruction to the desired level. If Toxic Substances Control Act (TSCA) design standards are used as a guideline, the afterburner and/or liquids incinerator minimum temperature would be increased to 1,200°C.

Residence time is the second critical parameter. Experience of rotary kiln vendors indicates that reactors capable of heating solids to a temperature approaching 1,000°C, and holding those solids temperatures for at least 30 minutes, ensure complete conversion of the organics into gas-phase molecules. Bulk gas residence times in the primary reactors greater than or equal to 2 seconds are required. Bulk gas residence times in the secondary reactor greater than or equal to 3 seconds are required. The 30-minute solids retention time is conservative. It must be recognized, however, that the organic contaminants are bound to clay, which has the ability to retain organic contaminants. Consequently, relatively long residence times are necessary to ensure 99.99 percent DRE. Short residence times for all of the material, or even a relatively small fraction of the material, could compromise such destruction.

TABLE 3.2-2

CRITERIA USED FOR TECHNOLOGY SELECTION

Criteria Categories	Parameters
Design/Operation	1) Reaction temperatures (a_1)
	2) Residence times (a_2)
	3) Designs with multiple process trains (a_3)
	4) Capability of handling feedstock with high clay content (a_4)
	5) Capability of handling feedstocks with varying particle size, moisture, specific gravity, and flow characteristics (a_5)
	6) Capable of minimizing loss of solids prior to achieving desired solids residence time (a_6)
Operator Safety	1) Negative pressure in combustors (b_1)
Environmental	1) Air pollution (c_1)
Maintenance	1) Rotating equipment (d_1)
	2) Refractory susceptibility (d_2)
	3) Arduous service for valves, instruments, and seals (d_3)
Cost	1) Capital cost (e_1)
	2) Operating cost (e_2)

Liquids are either mixed with the solids or injected directly into an afterburner, the fluidized bed freeboard space, or the secondary chamber in a hearth. These liquids also require a residence time of at least 3 seconds to evaporate, and to achieve 99.99 percent DRE. The TSCA standard, used only as a guideline here, is 2 seconds at 1,200°C.

The third critical factor is design capacity. To completely incinerate the Basin F hazardous wastes in 2.5 years assuming 80 percent availability, the unit must achieve the equivalent of fully operational status for 17,500 hours. Consequently, it must be capable of processing approximately 24 cu. yds/hr (or 32 tons/hr assuming 100 lb/ft^3) of soil. Therefore, a nominal minimum capacity requirement of 40 tons/hr appears reasonable. The system design includes two reactors, with a capacity of 20 tons/hr each.

The fourth design/operation factor is the capability of handling a solid waste with high clay content and/or significant quantities of sodium chloride and other salts. Summarized another way, the primary combustor must handle material that may swell, soften, and/or agglomerate. Chloride-containing compounds, such as calcium chloride and sodium chloride, exist in the liquid, and in the soils. These soils may soften and become "sticky" at low temperatures, or form eutectic mixtures with other solids, resulting in inert materials with low ash fusion temperatures. If the primary combustor cannot accommodate such materials, its reliability could be seriously compromised.

The fifth design/operation criterion is the capability of the system to handle widely variable wastes. The currently characterized waste stream includes both liquids and solids, with varying particle sizes and moisture contents. The range of particle sizes of materials tested exceeds two orders of magnitude, as previously shown in Figure 1.2-1. This range is from medium sand (≈20 percent) to fine sand (≈60 percent) to silt and clay (20 percent).

The final operating criterion is the minimization of solids losses. By assuming a uniform distribution of contamination in the soil and various levels of organic volatilization, a calculation can be made showing the impact of premature solids loss on DRE, assuming 100 percent destruction of the remaining materials. Such calculations are shown as a function of system DREs below (example calculations are provided in Appendix B).

Premature Soil Loss (Percent)	Volatilization Before Premature Solids Loss (Percent) [1]			
	50 Percent	90 Percent	99 Percent	99.9 Percent
10	95 DRE	99 DRE	99.9 DRE	99.99 DRE
7	96.5 DRE	99.3 DRE	99.93 DRE	99.993 DRE
5	97.5 DRE	99.5 DRE	99.95 DRE	99.995 DRE
3	98.5 DRE	99.7 DRE	99.97 DRE	99.997 DRE
1	99.5 DRE	99.9 DRE	99.99 DRE	99.999 DRE

[1] Defined as soil loss prior to the specified solids residence time.

Premature loss of soil must be held to a minimum (e.g., 1 percent) and volatilization must exceed 99 percent in the soil that leaves the reactor prematurely. Alternatively, volatilization of organics in the soil having short reactor residence time (leaving prematurely) must be at least 99.9 percent complete. Without those conditions, the system will not achieve an overall DRE of 99.99 percent.

These six design/operation considerations are treated almost as "fatal flaw" criteria. Failure to meet all of these criteria means that the system may fail to achieve its overall design objective.

3.4 OPERATOR SAFETY

All critical safety considerations must be designed into any incinerator contemplated for installation. As a consequence, the only safety criterion used to distinguish between technologies is the operation of combustors/reactors and all ancillary equipment at negative pressures. The use of negative pressures prevents leakage of volatiles and products of partial oxidation into the worker environment. Leaks that exist or develop result in the infiltration of air from the worker environment into the reactor/combustor. Negative pressures simplify the achievement of safety.

3.5 ENVIRONMENTAL

All hazardous waste incinerators produce particulates. Sulfur oxides and acid gases are produced to the extent of the concentration of sulfur, chlorine, and fluorine in the waste and supplemental fuel. All of these emissions can be controlled by a combination of wet scrubbers (e.g., condensing scrubbers, spray dryers, and venturi scrubbers), electrostatic precipitators, fabric filters, and the like. The primary concern is nitrogen oxide (NO_x), which is formed as a function of combustion temperature (thermal NO_x) as well as waste and supplement fuel composition (fuel bound NO_x). It is desirable to have reactors operating at less than 1,500°C in order to minimize thermal NO_x formation.

3.6 MAINTENANCE CONSIDERATIONS

Maintenance concerns impact both disposal costs (in $/ton) and unit reliability. Combustors susceptible to high maintenance requirements are far less desirable than essentially maintenance-free units.

Specific maintenance concerns are number of moving parts, susceptibility of refractory to erosion or corrosion, and service life of seals. Refractory is of particular concern due to the high salts content, particularly of the liquid. Maintenance remains an area for optimization of technology selection.

3.7 COST

The final criteria of importance are capital and operating costs. It is recognized that the cost criteria impact other evaluation parameters (e.g., auxiliary fuel and power requirements and operator requirements). These criteria have been impacted previously by design factors necessary to create appropriate regimes. At the same time, however, costs are sufficiently important that they are again treated here.

Capital costs include the design, construction, startup, and then ultimate disposition of the incinerator as built. For purposes of this analysis, order of magnitude costs for generic technologies are sufficient to determine "greater-than" or "less-than" values.

Operating costs include personnel, fuels, and common and extraordinary maintenance charges associated with functioning of the incinerator. Again, order of magnitude costs are sufficient for the analysis. These cost criteria will help ensure that the most cost-effective, technically correct, solution is obtained.

3.8 RANKING OF SCREENING CRITERIA

The evaluation technique used for ranking the screening criteria is discussed in the Task 17 Technical Plan (Ebasco 1987). The technique used was the paired comparison technique.

There were 13 parameters encompassing five criteria. To determine the weighting factor for each criterion category, these 13 parameters were evaluated through the paired comparison technique. For each comparison, a decision was made as to which parameter was more important. The more important parameter receive a score of 1, the less important a score of 0. If the parameters were of equal importance, each received a score of 0.5. The results of this comparative evaluation are presented in Table 3.8-1.

TABLE 3.8-1

RANKING OF PARAMETERS IN THE SCREENING CRITERIA

Parameters	a_1	a_2	a_3	a_4	a_5	a_6	b_1	c_1	d_1	d_2	d_3	e_1	e_2	Dummy
a_1	N/A [1/]	0	0	0	0	0.5	0	0	0	0	0	0	0	0
a_2	1	N/A	0	0	0	0.5	0	0	0	0	0	0	0	0
a_3	1	1	N/A	0	1	1	0	0	0	0	0	0	0	0
a_4	1	1	1	N/A	0.5	1	0	0	0	0	0	0	0	0
a_5	1	1	0	0.5	N/A	1	0	0	0	0	0	0	0	0
a_6	0.5	0.5	0	0	0	N/A	0	0	0	0	0	0	0	0
b_1	1	1	1	1	1	1	N/A	0	0	0	0	0	0	0
c_1	1	1	1	1	1	1	1	N/A	1	0	1	1	1	0
d_1	1	1	1	1	1	1	1	0	N/A	1	0.5	1	1	0
d_2	1	1	1	1	1	1	1	1	0	N/A	0	1	0	0
d_3	1	1	1	1	1	1	1	0	0.5	1	N/A	1	1	0
e_1	1	1	1	1	1	1	1	0	0	0	0	N/A	0	0
e_2	1	1	1	1	1	1	1	0	0	1	0	1	N/A	0
Dummy	1	1	1	1	1	1	1	1	1	1	1	1	1	N/A
TOTAL SCORE	12.5	11.5	9	8.5	9.5	12	7	2	2.5	4	2.5	6	4	0
NORMALIZED SCORE	0.137	0.126	0.099	0.093	0.104	0.132	0.077	0.022	0.027	0.044	0.027	0.066	0.044	0.0

1/ N/A = not applicable.

1177D

The weighting factor for each criterion was determined by adding the normalized scores of parameters that were part of the criterion. For example, the criterion "Design/Operation" comprises six parameters (a_1 to a_6) (See Table 3.2-2). Figure 3.8-1 depicts the criteria weighting results that indicate "Design/Operation" is the primary criterion for screening the incineration technologies. The weighting factors determined for design/operation, operator safety, cost, maintenance, and environmental criteria are 0.69, 0.08, 0.11, 0.10, and 0.02, respectively.

CRITERIA	WEIGHTING FACTOR
DESIGN/OPERATION	0.69
COST	0.11
MAINTENANCE	0.10
OPERATOR SAFETY	0.08
ENVIRONMENTAL	0.02

$$\text{DESIGN/OPERATION} = a_1 + a_2 + a_3 + a_4 + a_5 + a_6 = 0.69$$

$$\text{COST} = e_1 + e_2 = 0.11$$

$$\text{MAINTENANCE} = d_1 + d_2 + d_3 = 0.10$$

$$\text{OPERATOR SAFETY} = b_1 = 0.08$$

$$\text{ENVIRONMENTAL} = c_1 = 0.02$$

FIGURE 3.8-1
SCREENING CRITERIA WEIGHTING

4.0 DESCRIPTIONS OF INITIALLY SELECTED INCINERATION TECHNOLOGIES

This chapter presents a description of the preferred technologies for thermal treatment of Basin F materials. The descriptions include a discussion of system operation, problems specific to Basin F soils and liquids, size of commercial systems, and operating conditions.

4.1 DESCRIPTION OF PREFERRED TECHNOLOGIES

As discussed previously in Section 2.0, a wide variety of incineration or thermal oxidation/destruction technologies exists. However, only three are considered commercially available and capable of ensuring 99.99 percent DRE of the contaminated soils and other hazardous wastes at Basin F of Rocky Mountain Arsenal. As previously discussed, these technologies are the following:

- o Rotary kiln incinerators;
- o Fluidized bed incinerators; and
- o Hearth-type incinerators.

All three of these technologies can be used for the incineration of solids and liquids and are commercially available. Before these technologies are ranked using the selection criteria developed in Section 3.0, a more detailed discussion of each is in order.

4.2 ROTARY KILN INCINERATORS

Rotary kiln incinerators are widely used for hazardous waste applications. The waste material is charged into the kiln and travels along the kiln, propelled by the slope of the rotating cylinder, the diameter (hence, angle) of the cylinder, and the speed of rotation. It is discharged from the opposite end after burning. Rotary kilns are fueled by pulverized coal, oil, and natural gas. To date, coal has not been used as a fuel in

hazardous waste incinerators and is not considered in this analysis. The hazardous waste may be fed either at the end where the flame is located (cocurrent operation), or fed from the opposite end (countercurrent operation). Virtually all rotary kiln incinerators for hazardous waste operate in the cocurrent mode except for IT Corporation's and Vesta's mobile incinerators. Typically, rotary kiln incinerators for hazardous waste are refractory-lined cylinders that are 6-15 ft in inside diameter and 25-60 ft long. Figure 4.2-1 shows a schematic of a cocurrent rotary kiln. Dikeou (1980) reports that cement kilns may be as large as 25 ft in diameter and 200 ft long, although 15 ft is the largest practical size for shop fabrication.

Rotary kiln technology is conventional in such process industries as cement, minerals processing, alloy separation, and pulp and paper. For pulp and paper mills, rotary kilns are used for lime calcining, with the resulting lime used in the kraft process. Recently these systems have been applied to energy systems including coal gasification, municipal waste-to-energy, and hazardous waste destruction projects.

4.2.1 Hazardous Waste Rotary Kiln/Design Considerations

Hazardous waste rotary kiln systems normally include a feed system, the kiln itself, and an afterburner as shown in Figure 4.2-1. The flow of solids is typically cocurrent to the flame. The kiln and the afterburner must be operated at slightly negative pressures (e.g., 0.5 to 2 in., water column [in. W.C.]) to prevent problems associated with air leaks in seals or joints.

Hazardous waste kilns are fueled by waste solvents, light or heavy oil, propane, or natural gas. The flame typically is blown down the axis of the kiln, although other designs (e.g., the Allis-Chalmers kiln) may provide for fuel injection through the cylinder wall. Typically kilns may be operated at about 50 percent excess air (7.0 percent O_2 in the stack) to optimize temperature and combustion completeness. The range of excess air conditions reported by Keitz et al. (1984) is 30 to

FIGURE 4.2-1

FLOW SHEET OF AN INCINERATION PLANT FOR HAZARDOUS WASTES

Source: Babcock Krauss–Maffei Industrieanlagen GMBH (Revised by P. Adie).

100 percent, with Frankel et al. (1983) reporting 40 to 250 percent excess air. Typically kilns are designed to obtain some air through charging doors, rotary seals, and other sources of infiltration.

Kilns are capable of operating in the slagging mode. Kiln temperatures frequently are 900-1,250°C at the hot end depending upon design considerations, with recent designs having kiln temperatures in the slagging region of 1,310-1,540°C at the hot end (Keitz et al. 1984). Exit temperatures of product gases from rotary kilns depend upon the material being fed to the kiln; the type, quantity, and combustion conditions associated with the fuel for the kiln; the length of the kiln; the thickness and type of refractory employed; and whether the kiln is operated in a cocurrent or countercurrent mode. Exit temperatures for kilns may be as high as 900°C or as low as 320°C depending upon process, kiln length, and hot-end temperature.

Typical temperature profiles vary depending upon the point of hazardous waste feed. One of the major parameters in temperature selection is the refractory lining of the kiln. Many kilns typically are lined with 2-4 in. of insulating firebrick covered with 6 to 10 in. of low temperature, highly erosion-resistant firebrick. High temperature kiln designs use high temperature, erosion resistant firebrick covering the insulating firebrick (Keitz et al. 1984). Residence times in the kiln include both the solids and the product combustion gases. Residence times of the solids are governed by the kiln equation shown below:

$$T = (1.77 \times \theta \times L \times F)/(S \times D \times N) \qquad (4\text{-}1)$$

where T is residence time, θ is angle of repose of the hazardous waste or soil in degrees (taken at 35 degrees for sandy-type material), L is the length of the kiln in feet, F is a factor to adjust for constrictions within the kiln, S is the slope of the kiln (degrees), D is the inside diameter of the kiln (feet), and N is the rotational speed of the kiln in rpm.

Typically, F is taken as unity, unless obstructions exist within the kiln. Typical residence times for solids are up to 2 hours. Bulk residence times of the gaseous products depend upon the volume of the kiln, the quantity of fuel and combustion air fed to the kiln, and the (absolute) temperature in the kiln. In addition to bulk residence times, fast residence times sometimes are calculated in order to evaluate gas-phase reactions. Fast residence times are the minimum residence times for some gas-phase molecules within the entire feed and product streams. Fast residence times for gaseous molecules typically are about one-half of bulk residence times for gaseous molecules.

Critical to the success of rotary kiln technologies is the heat transfer mechanism from the kiln and its heat source to the material being incinerated. Assuming the use of heavy oil as fuel, heat transfer occurs by radiation and convection from the flame to the material being incinerated. Further, heat is radiated to the refractory lining of the kiln shell. Heat is then conducted from the kiln wall to the material being incinerated. Heat transfer efficiency, consequently, is reasonably high when rotary kilns are not overloaded with soils or other feedstocks. Typical loading levels are about 10 percent and range from 6 to 15 percent. Loading is calculated by cross sectional area of the kiln theoretically filled with material. Loading is calculated by the following equation:

$$Lo = (CFH/(60 \times FM \times A)) \times 100 \qquad (4-2)$$

where CFH is cubic feet per hour, FM is rate of travel of material in feet per minute, and A is cross-sectional area inside the refractory wall of the kiln in square feet. FM is defined by the shell length divided by the solids residence time. Lower loading percentages increase the heat transfer effectiveness of the kiln, but also increase the costs of operation due to capacity utilization.

Loading of the kiln is related to kiln dimensions and the consequent length/diameter (L/D) ratio. The L/D ratio is the length of the kiln divided by its inside diameter. Kilns are built with L/D ratios ranging from 3 to 15. Low L/D ratios reduce particulate emissions from kilns. Because of the small particle sizes of the soils, an L/D ratio of 3 to 4 is expected for the Basin F materials.

In the case of Basin F, the kiln would accomplish the volatilization of the hazardous organics from the soil or other matrices. Additionally, a small degree of combustion may occur in the kiln as the material is heated to high temperatures. After the material is subjected to the kiln environment, the product gases of the kiln are ducted to an afterburner with typical temperatures being 870-1,540°C, and bulk gas residence times averaging 2-3 seconds. The afterburner finalizes destruction of the gaseous products in order to maximize DRE.

Rotary kiln incinerators have the highest throughput capacities of the hazardous waste incinerators available and in service today. One vendor reports the manufacture of kilns capable of processing 25 tons/hr of contaminated soils. When burning incinerable wastes (wastes that achieve self-sustaining combustion), rotary kilns have achieved throughputs of 150 million Btu/hr. Rotary kilns processing bulk solids such as cement, lime for pulp mills, and ores for the mining industry have very large capacities. Dikeou (1980), for example, reports that cement kilns can have capacities of 140 tons/hr. For hazardous waste incineration, size is more a function of materials handling and subsequent system (e.g., afterburner) design and capital availability than any inherent limitation in the technology.

4.2.2 Afterburner Design Considerations

Rotary kiln designs all include afterburners, as previously discussed. These afterburners ensure complete oxidation of the gas-phase compounds evolved in the rotary kiln. These afterburners are also used to destroy liquid hazardous wastes; the liquids bypass the rotary kiln and are pumped directly into the afterburner.

Afterburners typically operate in the temperature range of
1,090-1,370°C. They maintain residence times of 1-3 seconds and
utilize excess air levels of 120-200 percent (Keitz et al. 1984).
These operating parameters are very similar to those quoted for liquid
injection incinerators:

| | Incinerator | |
Parameter	Kiln Afterburner	Liquid Injection
Minimum Temperature (°C)	1,090	980
Maximum Temperature (°C)	1,370	1,650
Minimum Time (seconds)	1	0.3
Maximum Time (seconds)	3	2
Excess Air (minimum percent)	120	120
Excess Air (maximum percent)	200	250

TSCA design parameters for such a device would include the following minimum
design parameters (if they are determined to be applicable):

Parameter		Design Standard	
Minimum Temperature (°C)	1,200		1,600
Residence Time (seconds)	2		1.5
Excess Air (percent dry excess O_2)	3.0		2.0

A total of 3 percent O_2 is equal to 17 percent excess air, while 2 percent
O_2 is equal to 11 percent excess air. These are minimum values.

In the case of incinerating wastes from Basin F, neither the gaseous
products from the rotary kiln nor the liquids from the basin can achieve
self-sustaining combustion. A supplemental fuel is therefore necessary. If
the afterburner is to be used, the liquids and gases must be injected after
the flame front. Such a point of injection prevents quenching of the
flame. The afterburner residence time governs the design for liquids
treatment and, particularly, the evaporation rate of the liquids. The
evaporation rate is governed by the following equation:

$$T = Do^2/S \qquad\qquad (4-3)$$

1314D

06/21/88

Where T is droplet evaporation time (seconds), Do is initial drop diameter (microns), and S is an evaporation constant. Normally, S is experimentally determined. For pure water it is 0.33 mm^2/sec. Solving this equation leads to the following residence times:

Droplet Diameter (microns)	Evaporation Time (seconds)
100	0.03
300	0.27
500	0.76

Given these data, the afterburner utilizes atomization of the liquid, prior to its injection, in order to limit the size of the reactor. The largest droplet diameter governs droplet size, rather than the mean diameter. Larger droplets take longer to evaporate and may "break through," preventing achievement of 99.99 percent DRE much like soils prematurely leaving the solids reactor.

The actual afterburner, like a liquid injection incinerator, should function as a well-stirred reactor at the region of the flame; and it should function as a plug flow reactor in the region of hazardous waste destruction. Typical parameters for its design would include a length/diameter ratio of about 4:1 and an exit gas velocity of 5,000 ft/min. In the case of this potential installation, the afterburner would be handling a high salt content waste, with consequent potential for damage to the refractory. Because of salt content in the liquid, it would be desirable to install the afterburner in a vertical orientation. Such an installation would provide for salts leaving the afterburner before they accumulate on the refractory. A schematic of an afterburner for a rotary kiln is shown in Figure 4.2-2.

4.2.3 Pollution Control Systems for Rotary Kilns

The final issue of importance is the airborne emission control system. Such systems include air quench, water quench, and waste heat boilers for temperature reduction. These are followed by venturi scrubbers, fabric
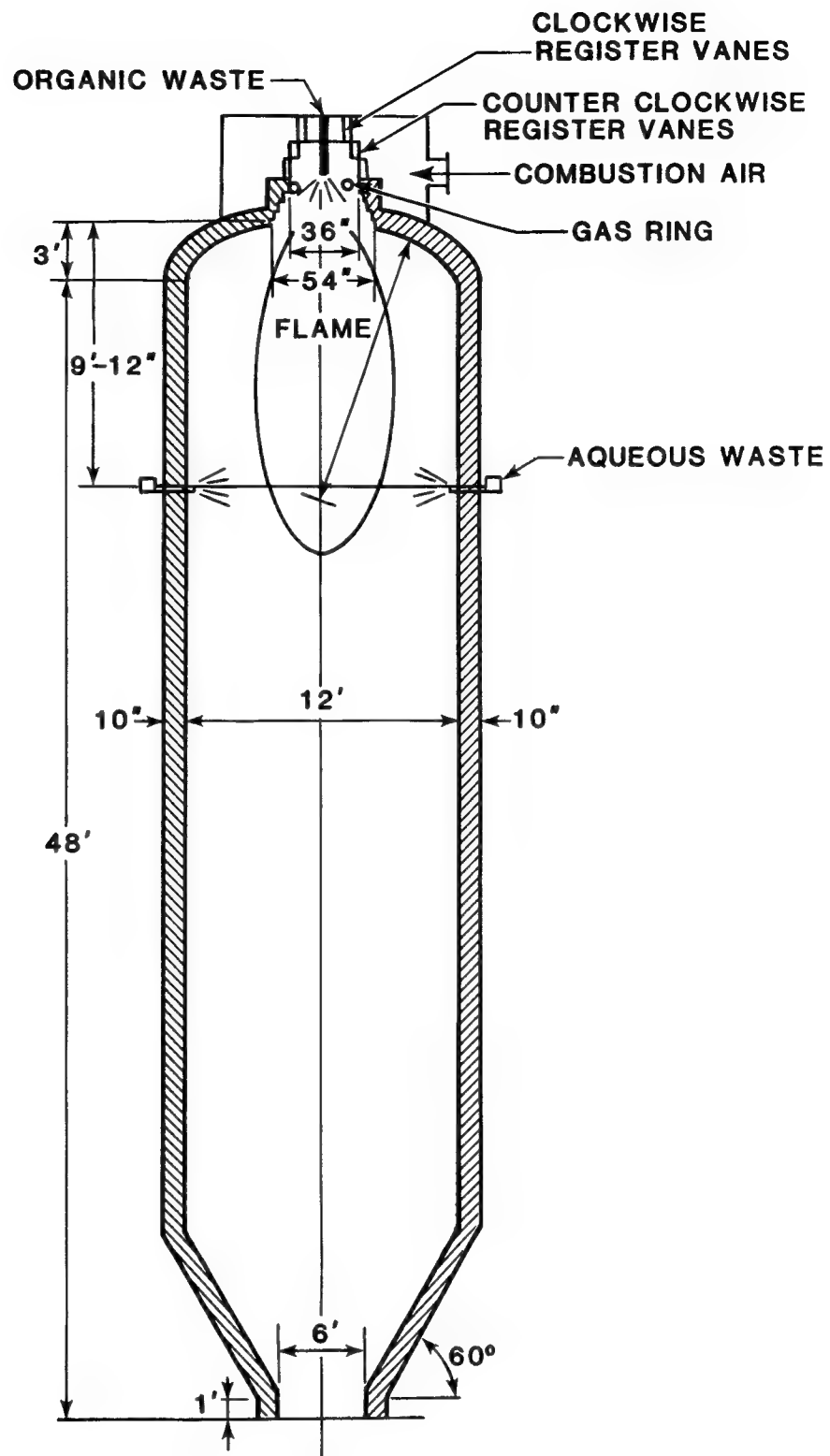
FIGURE 4.2-2
LIQUID WASTE AND AFTERBURNER INCINERATOR FURNACE

filters, and electrostatic precipitators for particulate removal, and finally by condensing wet scrubbers for removal of acid gases. Final selection of a particulate control system depends on the concentration of acid gases, particulate loading, outlet temperature from the afterburner, stack temperature, the degree of control required, and the need for process steam. There are numerous successful rotary kiln incinerator installations with acid gas scrubbers and particulate control devices.

The airborne pollution issue that is somewhat of a weak point with rotary kilns is NO_x emissions. NO_x is formed either by fixation of atmospheric nitrogen (thermal NO_x) or oxidation of any nitrogen contained in the fuel (fuel NO_x). In the case of the chemicals contained in Basin F, there is little nitrogen bound in the waste to be treated, although there is free ammonia and urea. Consequently, any fuel NO_x produced would come from the fuel burned to treat the contaminated soils and liquids and from the ammonia and urea. Fuel NO_x control is usually achievable by fuel selection plus proper operation of the system (e.g., some staging of combustion plus use of low excess air levels). Thermal NO_x formation is a consequence of the regime ultimately selected for hazardous waste destruction. However, since actual flame temperatures in rotary kilns are as high as 1,480-1,650°C, significant levels of NO_x may be reached.

4.3 FLUIDIZED BED INCINERATORS

A commercialized advanced technology alternative to the rotary kiln is the fluidized bed incinerator. The fluidized bed technology is well demonstrated. The Winkler coal gasifier supporting the Fischer-Tropsch reactors of Germany is an oxygen-blown fluidized bed reactor. Since then, fluidized beds are used in the combustion of coal, heavy oil, and a variety of other solid and liquid waste fuels. Fluidized beds are also used as particle dryers, as catalytic crackers in petroleum refiners, and in other applications.

There are several types of fluidized bed reactors, with the dominant ones being the conventional bubbling bed and the more advanced designs including the circulating fluidized bed system (such as that of Ogden Environmental Services). Conventional bubbling bed technology is depicted in Figure 4.3-1. The circulating fluidized bed technology is shown in Figure 4.3-2.

The basic principle of the fluidized bed system is best discussed in terms of Figure 4.3-1. There are three basic parts to the fluidized bed incinerator: 1) the windbox, 2) the bed, and 3) the freeboard space above the bed. During fluidized bed combustion, fuel is introduced into the reactor either within the bed or above the bed. The bed consists of noncombustible solid particles of a defined size and shape. The particles are limestone if a sulfur-bearing fuel is being burned, sand, or other special materials. Air is introduced under the bed to fluidize the bed media. Minimum fluidization occurs when the combustion air has only sufficient velocity to raise the bed particles. At or above minimum fluidization, the particles are kept in motion but, unless velocities are too great, blowout does not occur. Typical fluidizing air velocities are 0.2-5 ft per second for bubbling bed reactors.

Fluidized bed reactors are so named because the bed, in motion, behaves as a fluid. The bed maintains a uniform surface level, regardless of whether the vessel is tilted or completely vertically oriented. Further, the particles are in motion continuously, much like molecules in a liquid state. Circulating fluidized beds are operated at higher velocities, however. In circulating fluidized beds, particles on the surface of the bed achieve sufficient velocity to flow through the freeboard space and exit through the top of the reactor. Bed media particles are then captured in a cyclone and recirculated into the primary combustion chamber. Typically, bubbling beds are considered to operate as dense-phase reactors, while the top section of a circulating fluidized bed operates as a dilute-phase reactor.

4.3.1 Fluidized Bed Reactors as Incinerators for Basin F Materials

Fluidized beds have served as combustors for a wide variety of solid and liquid wastes. Typically, such wastes have sufficient calorific value to
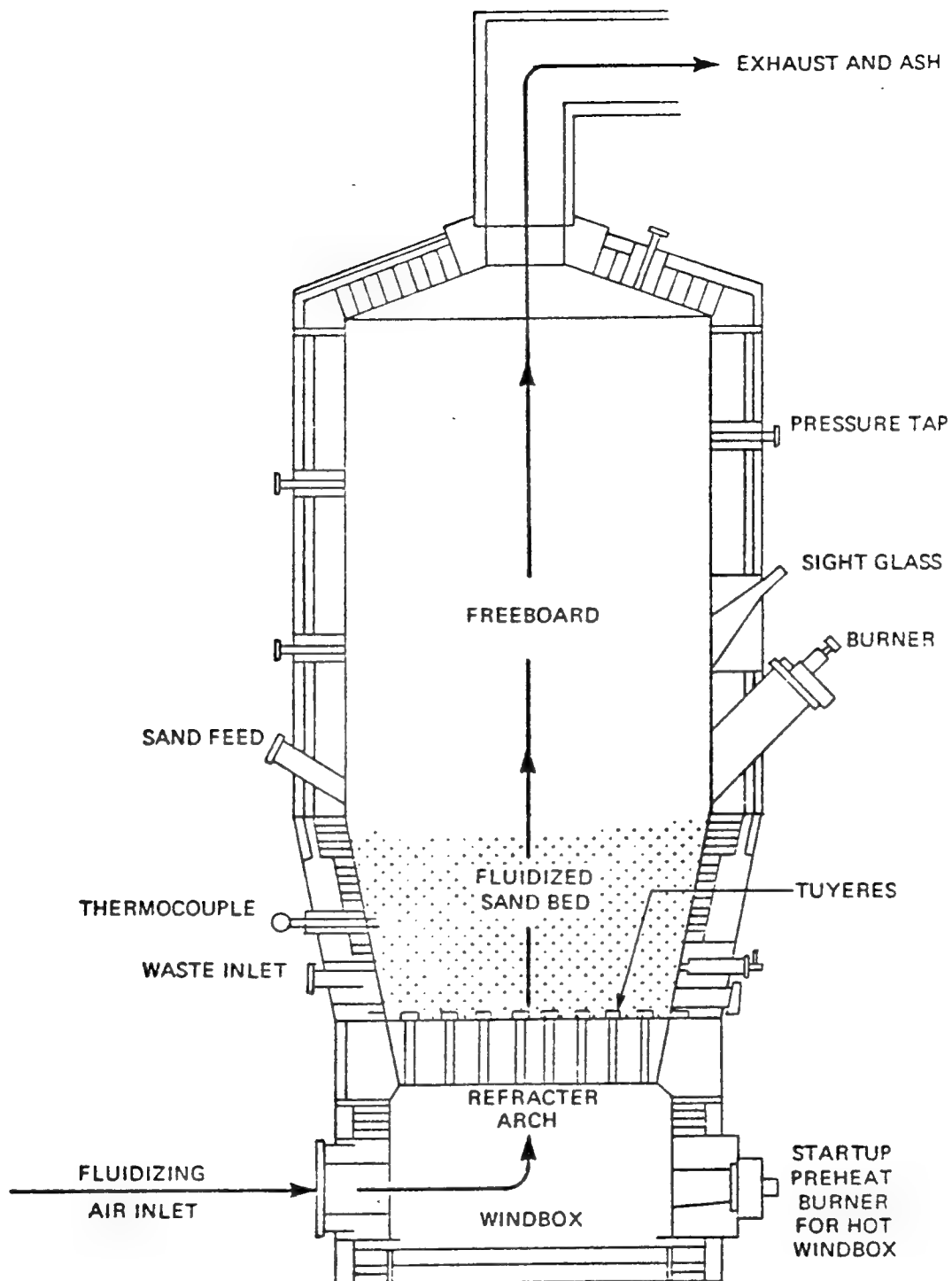
FIGURE 4.3-1
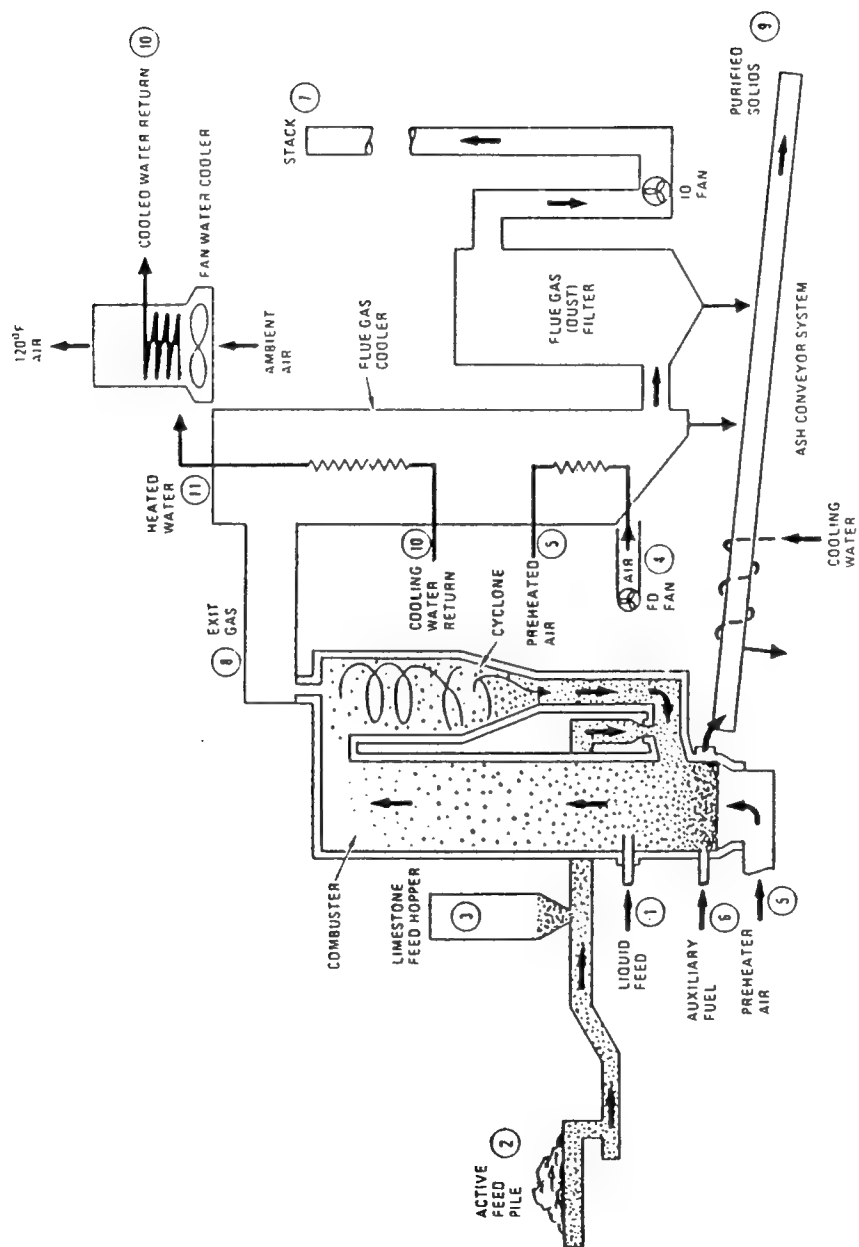**CROSS SECTION OF A FLUID BED FURNACE**

FIGURE 4.3-2

SCHEMATIC DIAGRAM OF A CIRCULATING FLUIDIZED BED FURNACE SYSTEM

support combustion as a self-sustaining reaction. Fluidized bed reactors, applied to Basin F wastes, would have to be operated in a different manner due to the nature of the materials to be thermally treated and decontaminated. Neither the solids nor the liquids contain any appreciable calorific content--they merit incineration only as a means of decontamination, pursuant to delisting. As a result, they must be incinerated by combustion with fossil fuels.

Because the solids and liquids at Basin F are not capable of supporting combustion, it is essential to define the problem carefully. The solids must be viewed as bed media. Consequently, the solids must be capable of behaving in a defined way. They must not swell, soften, or fuse during the combustion of solid fuels in the fluidized bed. The liquids must be injected with the solids, in relatively small quantities, or they must be incinerated separately. These problems, while not unique, are unusual for fluidized bed incineration.

4.3.2 Technical Parameters of Fluidized Bed Incinerators

Fluidized beds are either of the conventional dense-phase bubbling type, or of the circulating bed type as previously discussed. They may be fueled with any solid or liquid fossil fuel. They may use a variety of noncombustible materials as bed media. For purposes of hazardous waste incineration, fluidized bed incinerators have certain distinct advantages. Typically, they do not require afterburners. Fluidized beds typically have lower capital and operating costs per unit of capacity or production than rotary kilns. Further, fluidized bed systems have favorable maintenance costs relative to rotary kilns due to the absence of moving parts. The major cost penalty of such reactors is associated with the fan power required to fluidize the bed.

The combustion regime achieved by the fluidized bed may be less severe than that obtained in a rotary kiln. Frankel et al. (1983) report typical fluidized bed temperatures at about 750°C. Keitz et al. (1984) report a typical range of 780-1,110°C. The temperature range is limited by the

behavior (e.g., softening temperature) of the bed media and, secondarily, by the ash fusion temperature (e.g., softening temperature) of the fossil fuel being burned. The highest temperatures exist if a refractory sand is employed as the bed media and No. 2 distillate oil is employed as the fossil fuel. Freeboard zone temperatures usually are somewhat hotter than the bed temperatures, typically by about 50°C. A refractory sand-based fluidized bed, therefore, could be operated at temperatures approaching 1,170°C. Such a temperature regime may not be possible at RMA, however, particularly without extensive soils testing. For example, some of the salts existing in Basin F liquids or deposited in the soils have ash fusion temperatures as low as 800°C. The initial deformation temperature of the soils tested on average is 1,230°C.

Residence times available range from 1 to 5 seconds for gaseous molecules (Keitz et al. 1984). Typical values are in the 0.75 to 2.5 second range (Frankel et al. 1983). Solids residence times are varied based upon bed drawdown and related operating parameters.

Fluidized beds operate at levels of excess air ranging from about 25 percent to 150 percent depending upon the design. High levels of excess air are required if combustion air is used for temperature control (rather than heat removal from the bed). This air is required whether or not the combustion air is preheated (units using ambient air require less excess air). Keitz et al. (1984) report typical excess air levels at 100 to 150 percent. Such levels necessarily degrade the thermal efficiency of the unit relative to incinerators requiring 25 to 50 percent excess air. Fluidized bed units are typically operated at negative pressures of -1 in. W.C. (Frankel et al. 1983), eliminating the need for extensive seals. Any leakage about the reactors results in infiltration of air into the combustor rather than contamination of the working environment. Fluidized beds have far less problems with seals than do rotary kilns due to the absence of moving parts.

The heat transfer mechanisms and consequent rates associated with fluidized bed reactors are very high. Heat transfer is accomplished both by radiation and conduction from the burning fossil fuel particle or droplet to the bed

media particles. This heat transfer mechanism, coupled with bed agitation, provides for uniform temperatures throughout the bed, rather than a temperature gradient from a hot (flame) zone to a cooler exit. As mentioned previously, freeboard zone temperatures are likely to be slightly hotter than bed temperatures. The freeboard space is used in place of the afterburner.

Fluidized bed reactors are relatively high throughput devices. Frankel et al. (1983) report that fluidized bed incinerators burning about 15 tons/hr of waste (consumes 45.5×10^6 Btu/hr) have been installed. Units consuming up to 67×10^6 Btu/hr have also been built.

The fluidized bed incinerator, then, is a well-stirred reactor with bed particles agitated in order to achieve completeness of oxidation reactions. Fine particles become entrained in the combustion gases and exit to the cyclone or multiclone where 90 percent of the materials are captured and reinjected. Entrainment could be severe with a fine particle feed.

When solids are treated, the fluidized bed operates as a continuous reactor--feeding fresh soils in and simultaneously withdrawing the treated soils. Because of the nature of bed particle action, however, withdrawals from the bed are not exclusively spent or treated soils. There is some distribution (probably a normal distribution) of fresh, spent, and "overspent" materials in the withdrawals. If the system is designed for a mean residence time of 30 minutes, some fraction of the material in the drawdown will have spent less than 1 minute in the reactor, while an approximately equal fraction will have spent more than 60 minutes in the active bed. The percentages of fresh material leaving the bed before volatilization of organics occurs will vary depending upon the designated residence time.

The combined effect of fine particle entrainment and bed drawdown is expected to cause a relatively high level of premature solids loss. Entrainment could easily capture 10 percent of the bed particles assuming the particle size distribution shown previously. This would result in a

1 percent solids loss, assuming 90 percent particle capture and
reinjection. Similarly, the bed drawdown could result in the "fast" removal
of 1 percent of (untreated or partiality treated) solids. The consequence
is considerable difficulty in meeting the 99.99 percent DRE objective
without increasing the mean residence time.

When operating on Basin F waste, the fluidized bed incinerator would require
additional systems in order to screen particles for size. Oversize (e.g.,
>3/4 in.) particles would need to be screened and then crushed prior to
injection into the bed. The screening and crushing operation would have to
be run in such a way that all fugitive dust emissions were controlled.
Further, all air passing through this system would have to be used as
combustion air in order to prevent the escape of hazardous compounds.

4.3.3 Airborne Emissions from Fluidized Bed Incinerators

Fluidized bed incinerators produce various levels of airborne emissions
depending upon the fuel being combusted, the bed media, and the combustion
regime. Particulate emissions are higher than those associated with rotary
kilns, due to the potential for bed media to be carried out as fly ash.
Sulfur oxides are produced in direct proportion to the sulfur content of the
fuel and the waste burned. The production of sulfur oxides also is a
function of the bed media chosen (e.g., limestone) and the calcium/sulfur
molar ratio. Sulfur bound up as calcium sulfate is thermally stable and
does not produce sulfur dioxide. Oxides of nitrogen (NO_x) are produced as
a function of the nitrogen content of the material injected into the
fluidized bed. Because fluidized bed reactors operate at temperatures of
less than 1,500°C, thermal NO_x is not produced in significant quantities.
In that regard, fluidized beds have some advantage over rotary kilns. Other
acid gases are produced as a function of the chlorine and fluorine content
of the waste.

While fluidized bed incinerators can produce a variety of pollutants, they
are all readily handled by existing pollution control technologies (see Gin
et al. 1982) as previously discussed.

4.4 HEARTH-TYPE HAZARDOUS WASTE INCINERATORS

The third type of hazardous waste incinerator potentially applicable to Basin F materials is the hearth-type incinerator. Numerous hearth incinerator designs exist, including fixed single hearths and multiple hearths. Hearth-type furnaces have existed for many years and have been used to combust a wide variety of materials from wood and wood waste to bagasse, coffee grounds, sewage sludge, and other solid cellulosic materials. Such reactors are known not only as hearth furnaces but also as Dutch Ovens, Dietrich Cells, and similar designations. Typical hearth incinerator schematics are shown in Figures 4.4-1 and 4.4-2.

4.4.1 Design Principles of Hearth-Type Incinerators

In principle, the hearth-type furnace operates like all grate-fired combustors. The solid material to be treated is placed on the primary chamber grate. It is ignited and burned to completion. Gases evolved from the primary chamber combustion (or pyrolysis) are burned to completion in the secondary chamber (see Figure 4.4-1). The secondary chamber only involves gaseous compound incineration and does not treat solids. In the case of Basin F solids, the soils would have to be mixed with a fuel before being placed on the primary chamber grate or hearth. With sufficient soil-fuel mixtures, ignition and combustion could be maintained and the soil could be incinerated. Liquids might be mixed with the soils and solid fuel (e.g., heavy oil) or they could be burned in a separate liquid injection incinerator.

4.4.2 Design and Operation Considerations

Hearth-type incinerators achieve two different temperatures: primary chamber and secondary chamber temperatures. Typically, values achieved in the primary chamber of fixed hearth incinerators are reported to be 650-1,000°C, while temperatures achieved in the secondary chamber are reported at about 780-1,220°C (Keitz et al. 1984). The temperatures
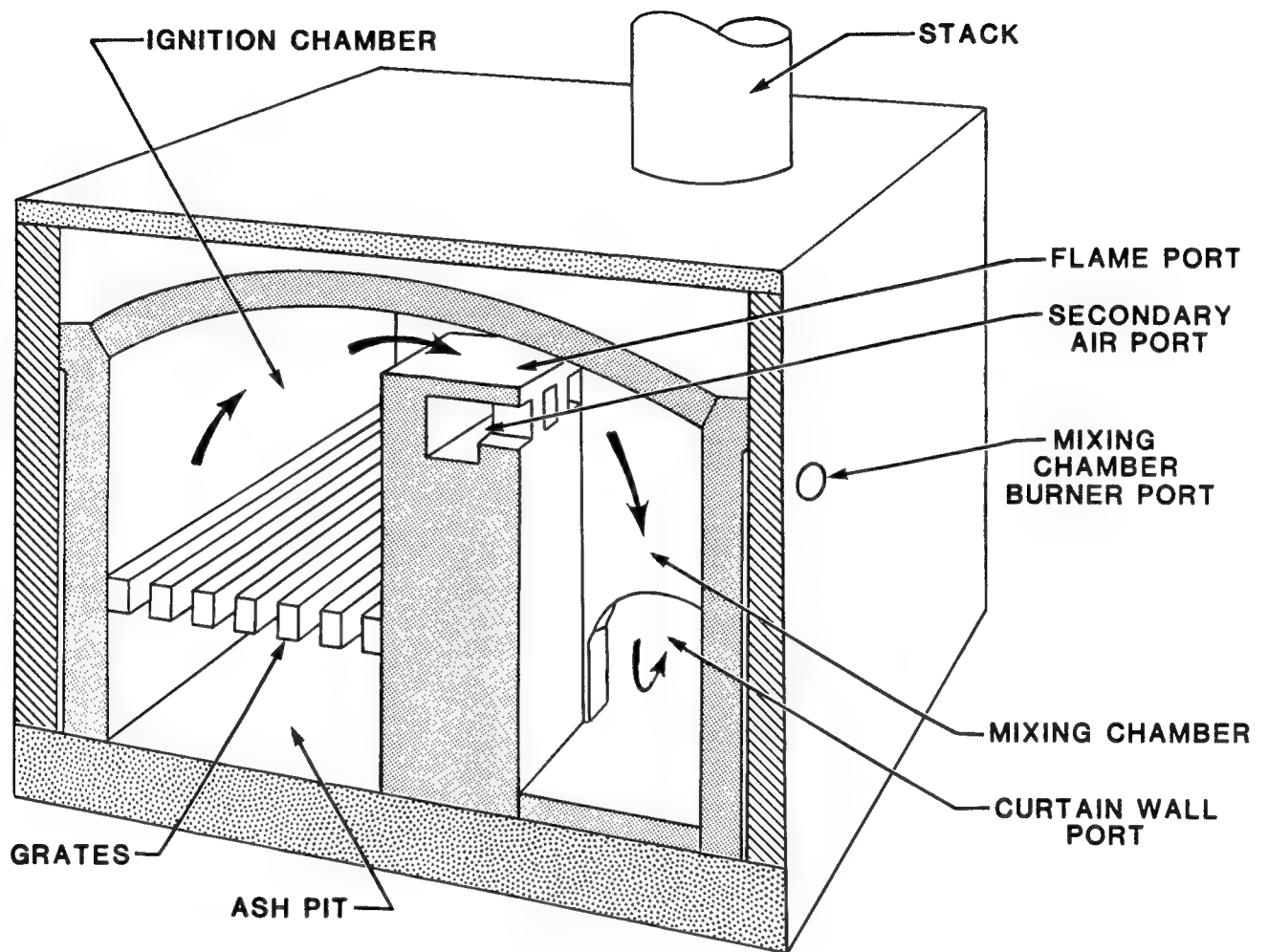
FIGURE 4.4-1
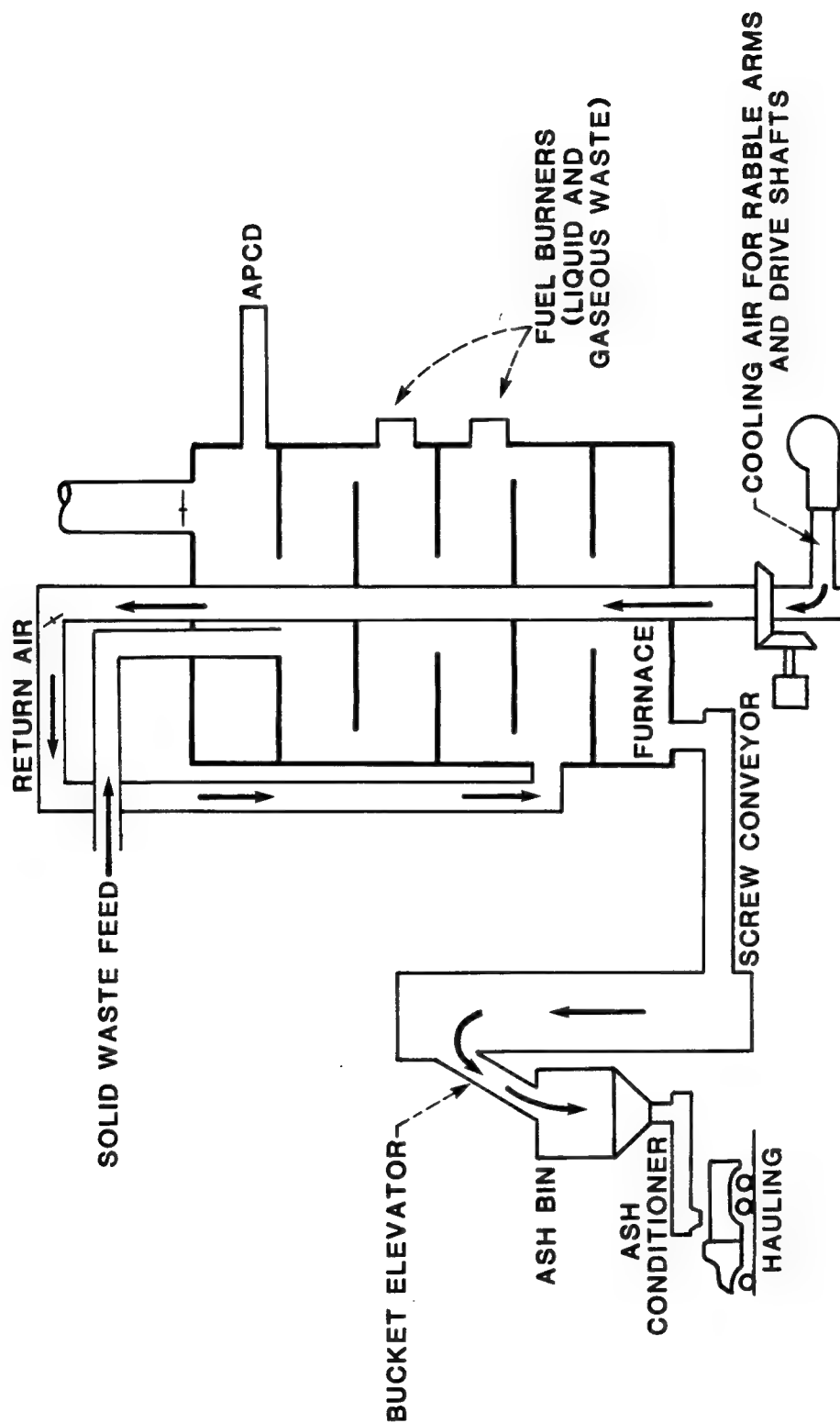**RETORT MULTIPLE-CHAMBER INCINERATOR**

4-19

FIGURE 4.4-2

TYPICAL MULTIPLE HEARTH INCINERATOR SCHEMATIC

reported by Frankel et al. (1983) are somewhat lower than those reported by Keitz et al. (1984). Frankel et al. (1983) report fixed hearth units having temperatures of 330-900°C in the primary chamber and 670-1,000°C in the secondary chamber.

At the same time, Frankel et al. (1983) report rotary hearth temperatures exceeding fixed hearth incinerator temperatures. Primary chamber rotary hearth temperatures are reported at 560-890°C, while secondary chamber temperatures are reported at 1,000-1,560°C.

Temperatures depend upon the fuel or waste being fired, and the excess air regime. Keitz et al. (1984) report levels of excess air at 30-200 percent in the primary chamber and 200-400 percent in the secondary chamber. Hearth-type incineration units also operate with substoichiometric quantities of air fed to the primary chamber, followed by complete combustion in the secondary chamber. When operated in such a mode, the primary chamber is a pyrolysis reactor. Relatively low excess air levels are required in the secondary chamber to achieve the temperatures reported for rotary hearth designs. Temperatures in the primary chamber are limited by the ash fusion temperature of the material being incinerated, and the fuel used to achieve incineration. Eutectic effects between the fuel ash and the RMA Basin F dirt also must be accommodated in setting any such temperature regime.

Residence times achievable in hearth-type incinerators are reported at 10-30 minutes for solids in the primary chamber of the rotary hearth incinerator and 2 seconds in the secondary chamber of both hearth-type incinerators (Frankel et al. 1983). The range of residence times reported for secondary chambers by Keitz et al. (1984) is relatively narrow: 2.5-3.5 seconds.

Hearth-type incinerators may be operated either at positive or negative pressures. Frankel et al. (1983) report pressures in rotary hearth incinerators at +0.5 in. W.C. and pressures in fixed hearth incinerators at

-0.2 or +0.2 in. W.C. Positive pressure units require considerable
attention to seals and leaks to prevent contamination of the working
environment.

Throughput levels of hearth-type incinerators are lower than those
associated with rotary kilns or fluidized beds. Frankel et al. (1983)
report incineration capacities of 0.013-1.25 tons/hr for fixed hearth
incinerators. The rotary hearth capacities that are feasible, according to
one quoted manufacturer, are 1.8-12 tons/hr (Frankel et al. 1983). Fixed
hearth incinerators, therefore, are inadequate due to capacity limitations.

4.4.3 Airborne Emissions Associated with Hearth-Type Incinerators

Like rotary kilns and fluidized beds, hearth-type incinerators produce
particulates, oxides of sulfur, oxides of nitrogen, and acid gases in
relation to the combustion regime. While such emissions may be produced,
technologies are available to provide adequate control.

4.5 INCINERATION COSTS

Relative costs of incinerators have been obtained for both rotary kiln and
fluidized bed technologies. These costs are presented below in
February 1986 dollars and are for a 65,000 ton/yr (100 x 10^6 Btu/hr)
facility. These costs are relative for a given sized unit and, as such,
cannot be used to calculate cost per ton of material incinerated. This cost
is calculated based on the Full-Scale Conceptual Design Report (Ebasco 1988).

	Cost	
	Capital	Annual Operating and Maintenance
Rotary Kiln	$7,630,000	$2,540,000
Fluidized Bed	$3,550,000	$510,000

The above costs were updated to 1986 dollars based on the Chemical
Engineering Magazine Plant Cost Index. These incinerator costs are somewhat
low. Bonner et al. (1981) report rotary kiln capital costs at about
12.2×10^6, updated to 1986 dollars, for a comparably sized system.
Variation may come from a variety of sources including the type of waste
consumed and the type of fuel burned. Bonner et al. (1981) also provide an
exponential scale factor of 0.6 for the installed capital costs of rotary
kilns.

The fluidized bed system costs are somewhat optimistic. As previously
stated, fluidized bed systems typically do not include an afterburner in
their cost estimate. Further, a screening and crushing operation would be
required. The capital cost ratio for the fluidized bed and rotary kiln
capital costs given above is calculated at 0.47:1. If the afterburner and
materials handling are included, the more appropriate ratio is 0.65:1.

Although there is a wide variation between the relative cost estimates, the
relative cost differences between rotary kilns and fluidized beds provide a
basis for ranking of alternatives. Hearth furnaces have costs that are
somewhat higher than fluidized bed costs.

5.0 RANKING OF PREFERRED INCINERATION TECHNOLOGIES

The purpose of this chapter is to rank the rotary kiln, fluidized bed, and hearth-type incineration technologies in order to select the system that is most appropriate for use on Basin F wastes.

5.1 RANKING OF TECHNOLOGIES

The above technologies are ranked based on the description presented in Chapter 4.0 and the description of the paired comparison technique in Chapter 3.0. The established criteria for comparison and their respective weights are summarized below:

Criteria	Weight
Design/Operation	0.69
Operator Safety	0.08
Cost	0.11
Environmental	0.02
Maintenance	0.10

The results of the paired comparison technique for ranking the technologies are presented in Table 5.1-1. The results include the total and normalized scores for each of the criterion. The normalized scores are then multiplied by the above weight factors. These scores are then summed for all of the criteria for each of the three technologies. These results are summarized in Table 5.1-2 and presented below:

Rotary Kiln	1.00
Fluidized Bed	0.88
Multiple Hearth	0.44

TABLE 5.1-1

RANKING OF TECHNOLOGIES WITH RESPECT TO
SELECTED CRITERIA

Technologies	Rotary Kiln	Fluidized Bed	Multiple Hearth
Design/Operation			
Rotary Kiln	N/A[1/]	0	0
Fluidized Bed	1	N/A	0
Multiple Hearth	1	1	N/A
Dummy	1	1	1
Total Score	$\overline{3}$	$\overline{2}$	$\overline{1}$
Normalized Score	0.50	0.33	0.17
Operator Safety			
Rotary Kiln	N/A	1	0
Fluidized Bed	0	N/A	0
Multiple Hearth	1	1	N/A
Dummy	1	1	1
Total Score	$\overline{2}$	$\overline{3}$	$\overline{1}$
Normalized Score	0.33	0.5	0.17
Cost			
Rotary Kiln	N/A	1	1
Fluidized Bed	0	N/A	0
Multiple Hearth	0	1	N/A
Dummy	1	1	1
Total Score	$\overline{1}$	$\overline{3}$	$\overline{2}$
Normalized Score	0.17	0.50	0.33
Environmental			
Rotary Kiln	N/A	0.5	0.5
Fluidized Bed	0.5	N/A	0.5
Multiple Hearth	0.5	0.5	N/A
Dummy	1	1	1
Total Score	$\overline{2}$	$\overline{2}$	$\overline{2}$
Normalized Score	0.33	0.33	0.33

06/21/88

TABLE 5.1-1 (Continued)

RANKING OF TECHNOLOGIES WITH RESPECT TO
SELECTED CRITERIA

Technologies	Rotary Kiln	Fluidized Bed	Multiple Hearth
Maintenance			
Rotary Kiln	N/A	1	0
Fluidized Bed	0	N/A	0
Multiple Hearth	1	1	N/A
Dummy	1	1	1
Total Score	2	3	T
Normalized Score	0.33	0.5	0.17

1/ N/A = not applicable.

TABLE 5.1-2

RANKING OF PREFERRED INCINERATION TECHNOLOGIES

| Criteria | Technologies | | |
	Rotary Kiln	Fluidized Bed	Multiple Hearth
Design/Operation	0.345	0.228	0.117
Operator Safety	0.026	0.040	0.014
Cost	0.019	0.055	0.036
Environmental	0.007	0.007	0.007
Maintenance Considerations	0.033	0.050	0.017
Total Score	0.430	0.380	0.191
Normalized Score	1.000	0.880	0.440

5.2 CONCLUSION

In conclusion, rotary kiln technology is best suited for Basin F wastes since it has the highest probability of technical success given the nature of the material being incinerated. Rotary kiln technology is capable of providing the combustion regime necessary for a 99.99 percent DRE with minimum premature solid particle losses. Solid particle losses are minimized by low L/D ratios. Further, the rotary kiln is capable of handling the widest variation in feedstock without extensive material processing requirements and without major risk of transient or upset conditions.

The fluidized bed, while finishing a strong second in the overall ranking, is particularly weak in the design/operation criterion. The fluidized bed uses the contaminated soils as a bed media. This practice has the potential for inducing erosion problems, due to the fine particle size of the soils, the potential for bed softening and eutectic effects, and the potential for premature evacuation of the contaminants from the reaction chamber. The fluidized bed may not achieve the desired (solids) residence times without constructing very large systems. Finally, the soils feeding system would require size reduction because of the inability to handle large particle sizes.

The multiple hearth technology scored the lowest mainly because of a low score for the design/operation criterion. Reasons for the low score for the design/operation criterion include the following: inability to handle the required volumes of material; the need for extensive feed preparation including size reduction; problems with salt melting and eutectic effects; and concerns regarding corrosion of the grates, rabble arms, and teeth. As a result, the multiple hearth technology is not selected.

As a result, the rotary kiln/afterburner is selected as the technology for which a system design, capital cost, operating and maintenance costs, and schedule are developed in the Full-Scale Conceptual Design Report.

Comments on this report were received from both EPA Region VIII and Shell Oil Company. These comments and the responses are presented in Appendices C and D, respectively.

Appendix A

# Fundamentals of Combustion Applied
To Basin F Wastes

APPENDIX A

FUNDAMENTALS OF COMBUSTION APPLIED TO BASIN F WASTES

INTRODUCTION

Incineration of the wastes contained in Basin F of Rocky Mountain Arsenal is characterized by low concentrations of highly toxic materials. Further, laboratory tests show that Basin F liquids and soils contain only 4 Btu/lb and 37 Btu/lb, respectively, comprising a feedstock with virtually no calorific value. These characteristics mandate a review of the fundamentals of combustion, particularly as they influence the selection of a regime for operating the full-scale incinerator. Such a review is presented in summary form in Chapter 3.0 and is amplified in this appendix.

Combustion is simply the oxidation of reduced materials, typically carbon and hydrogen, in either air or oxygen. Simplistically, it is represented by the following chemical equation for hydrocarbons:

for simple hydrocarbons:

$$C_xH_y + (X + \frac{Y}{4})O_2 \;---\; xCO2 + (\frac{Y}{2})H_2O \tag{A-1}$$
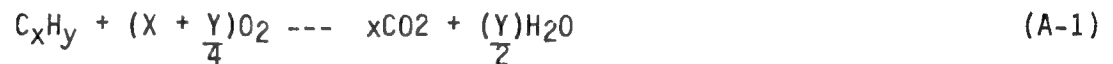
a balanced equation for ethane:

$$C_2H_6 + 7/2\ O_2 \;---\; 2\ CO_2 + 3H_2O \tag{A-2}$$
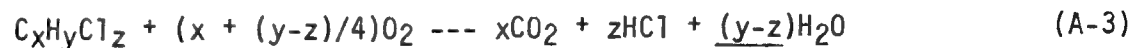
A simplistic example of a balanced combustion equation for a chlorinated hydrocarbon is presented below:

for chlorinated (or other halogenated) hydrocarbons (with y >z):
$$C_xH_yCl_z + (x + (y-z)/4)O_2 \;---\; xCO_2 + zHCl + \underline{(y-z)}H_2O \tag{A-3}$$

a balanced equation for chloromethane:

$$CH_3Cl + 3/2\ O_2\ \text{---}\ CO_2\ HCl + H_2O \tag{A-4}$$

These equations depict combustion in a simplistic fashion. In reality, combustion or incineration is highly complex and involves a substantial number of chemical and physical mechanisms and processes. Further, when combustion is applied to low concentrations of constituents in a nonreactive medium, the process becomes still more complicated.

It is important to review the mechanisms and pathways of hazardous waste combustion particularly as applied to the contaminants found in the soils and liquids at Basin F. Of particular importance is the consideration of mechanisms as they relate to the contaminated soils.

GENERAL MECHANISMS OF INCINERATION APPLIED TO BASIN F SOILS

Chemically, combustion or thermal oxidation is a free radical process. The combustion reactions can occur either as a sequence of gas-phase reactions or as a combination of gas-phase and gas-solids reactions. Given the organic compounds identified in Tables 1.2-2 and 1.2-3, it is expected that all reactions associated with the thermal oxidation reactions of the dilute hydrocarbons and halocarbons containing Basin F soils occur in the gas phase (gas-solids combustion reactions typically are limited to pyrolysis of either coal or other solid fuels and to the oxidation of the chars evolved from the coal or solids pyrolysis).

In the combustion or incineration of wastes from Basin F soils, the bulk solids are heated to temperatures necessary to evolve the contaminants as gases. As can be seen from Table 3.1-1, once completely heated to temperatures in the 500-1,000°C range, the chemical contaminants in the bulk solids enter the gas phase either by boiling, sublimation, or pyrolysis. When the contaminants are in the gas phase they undergo additional pyrolysis or bond rupture, producing free radicals and atoms that further react in the

combustion process. The bond rupture of hydrocarbons, rather than cleavage of the O=O oxygen double bonds (for diatomic oxygen in the air), is the probable chain initiation step in combustion. Typically, bond dissociation energies are lower for the carbon-carbon or carbon-hydrogen bonds. Similarly, dissociation of moisture contained in the reactants is not considered a likely chain initiation step.

Once chain initiation occurs, and oxygen is available from the air, the process of thermal oxidation begins. This is the chain propagation stage of combustion. In the actual flame, a radical rich environment exists.

The dominant reactions in this region are hydroxy radical abstraction reactions. In the post-flame region, thermal oxidation reactions proceed to completion in the sequence of chain termination reactions. Radicals and fragments combine into compounds of complete combustion (e.g., CO_2 and H_2O), and some products of incomplete combustion (PICs). This generic mechanism is summarized in Figure A-1.

It is generally believed that, in hazardous waste combustion or incineration, 99 percent of destruction occurs within the flame. The destruction efficiency of the flame results from its high temperature and reactive environment, characterized by high concentrations of hydroxy radicals. Achieving 99.99 percent destruction and removal efficiency (DRE) requires an additional 99 percent destruction of remaining compounds in the post-flame region.

KINETIC CONSIDERATIONS IN HAZARDOUS WASTE INCINERATION

Critical among the combustion chemistry considerations are the kinetics associated with the thermal oxidation of dilute concentrations of hazardous wastes. The kinetics of such thermal destruction vary with the overall mechanism involved, specifically: 1) pyrolysis, 2) flame oxidation, and 3) post-flame reactions.
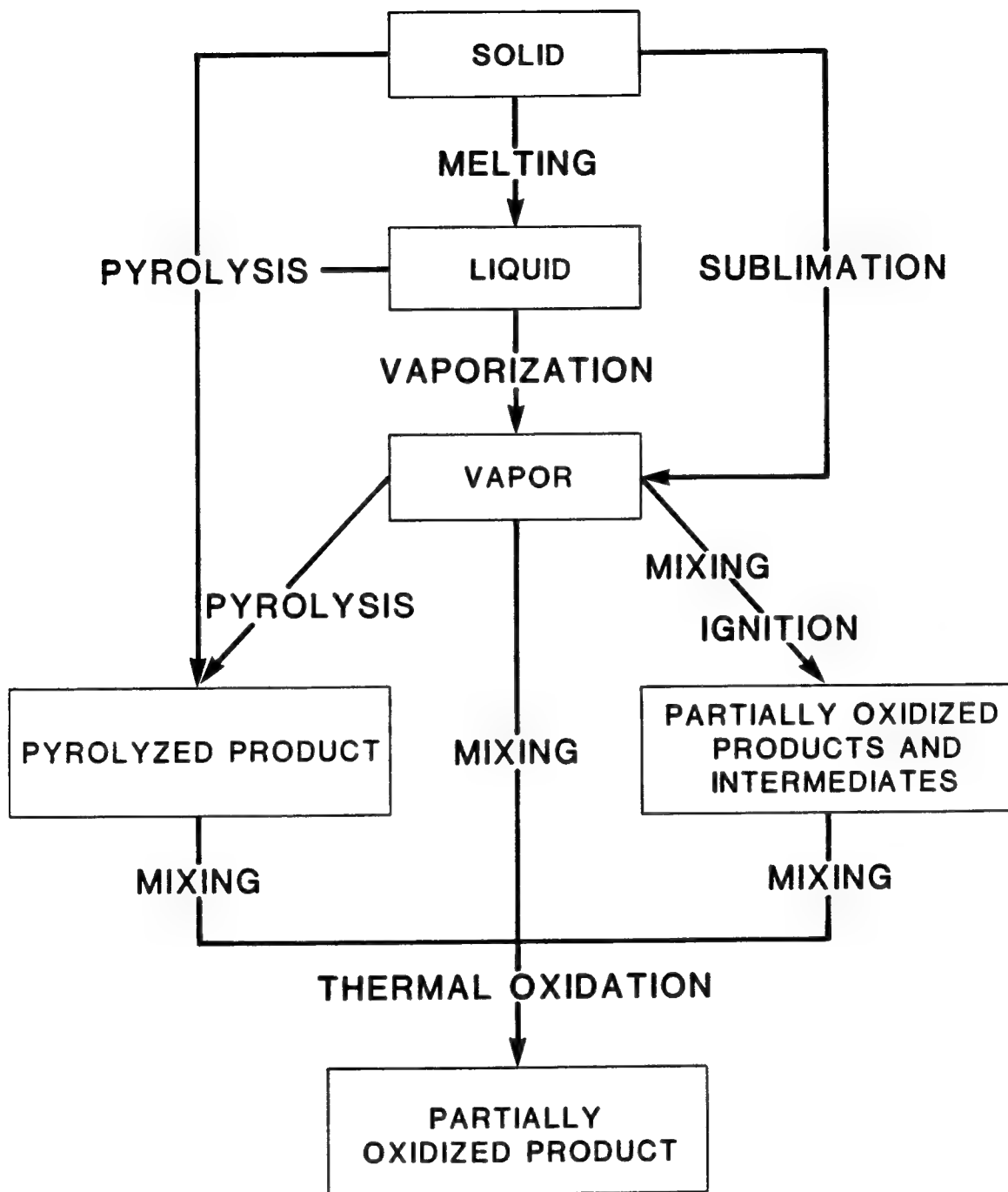
FIGURE A-1

SCHEMATIC DIAGRAM OF PROCESSES OCCURRING DURING THE DESTRUCTION OF A SOLID WASTE

Most kinetic studies of hazardous waste incineration use first order kinetics, or pseudo first order kinetic approximations. Typically destruction rates are related to the general Arrhenius equation:

$$k = A \exp(-E_a/RT) \qquad (A-5)$$

where k is the average rate constant, A is the Arrhenius coefficient (also known as the pre-exponent frequency factor), E_a is the activation energy for the process (cal/mole), and R is the universal gas constant. The process of destruction is expressed as two conceptual equations, one for pyrolysis and one for thermal oxidation in oxygen rich flame and post-flame environments. The pyrolysis reaction is shown as equation A-6 and the oxidation reaction is shown as equation A-7 (Dellinger et al. 1984).

Pyrolysis:

$$aC \xrightarrow{\quad k_1 \quad} \text{products} \qquad (A-6)$$

Oxidation:

$$bC + cO_2 \xrightarrow{\quad k_2 \quad} \text{products} \qquad (A-7)$$

In the above equations, C is the concentration of any hazardous compound; O_2 is the concentration of oxygen; a, b, and c are the stoichiometric coefficients for the global reactions; and k_1 and k_2 are the global rate constants for pyrolysis and oxidation, respectively. These equations lead to the general expression for the rate of disappearance of any hazardous compound as shown in equation A-8:

$$-d(C)/dt = k_1(C)a + k_2(C)b(O_2)c \qquad (A-8)$$

In the above equation, time dependence is expressed directly in the equation and temperature dependence is considered by k_1 and k_2. In an oxygen-rich (i.e., incineration) environment, Equation A-8 is simplified to the following expression:

$$-d(C)/dt = k_2, \; (C) \qquad\qquad\qquad (A-9)$$

In the above equation, k_2, is a new pseudo first order rate constant. The impact of pyrolysis on destruction largely can be considered negligible because the oxidation reactions dominate the system. Pyrolysis reactions, therefore, can be ignored. Upon integration, this leads to a final equation:

$$fr = \exp\,(-k_2, \; tr) \qquad\qquad\qquad (A-10)$$

In the above equation, fr is the fraction of the parent hazardous compound remaining after incineration, and tr is the mean residence time in the reactor.

The kinetics of hazardous waste destruction can be shown as a series of curves, such as the one for chloroform ($CHCl_3$) developed by Dellinger et al. (1984) and shown in Figure A-2. Below a certain temperature, referred to as T_{onset}, virtually no destruction occurs. When T_{onset} is reached or exceeded, the compound is reactive and, typically, volatilization begins. T_{onset} typically is equivalent to the temperature where pyrolysis or sublimation is initiated. Above this temperature (of reactions), DRE levels increase logarithmically as a function of temperature for any given residence time. The relative importance of time and temperature are also shown in Table A-1 for a representative compound, chloroform ($CHCl_3$). This table highlights the importance of maximizing temperature to facilitate the destructive mechanisms of thermal oxidation.

This is a very brief summary of the kinetic concerns associated with hazardous waste destruction. The concerns give rise to the development of specific environment or regime-related DRE data, such as the destruction considerations shown in Table A-2 (the results of the Dellinger et al.

1317D
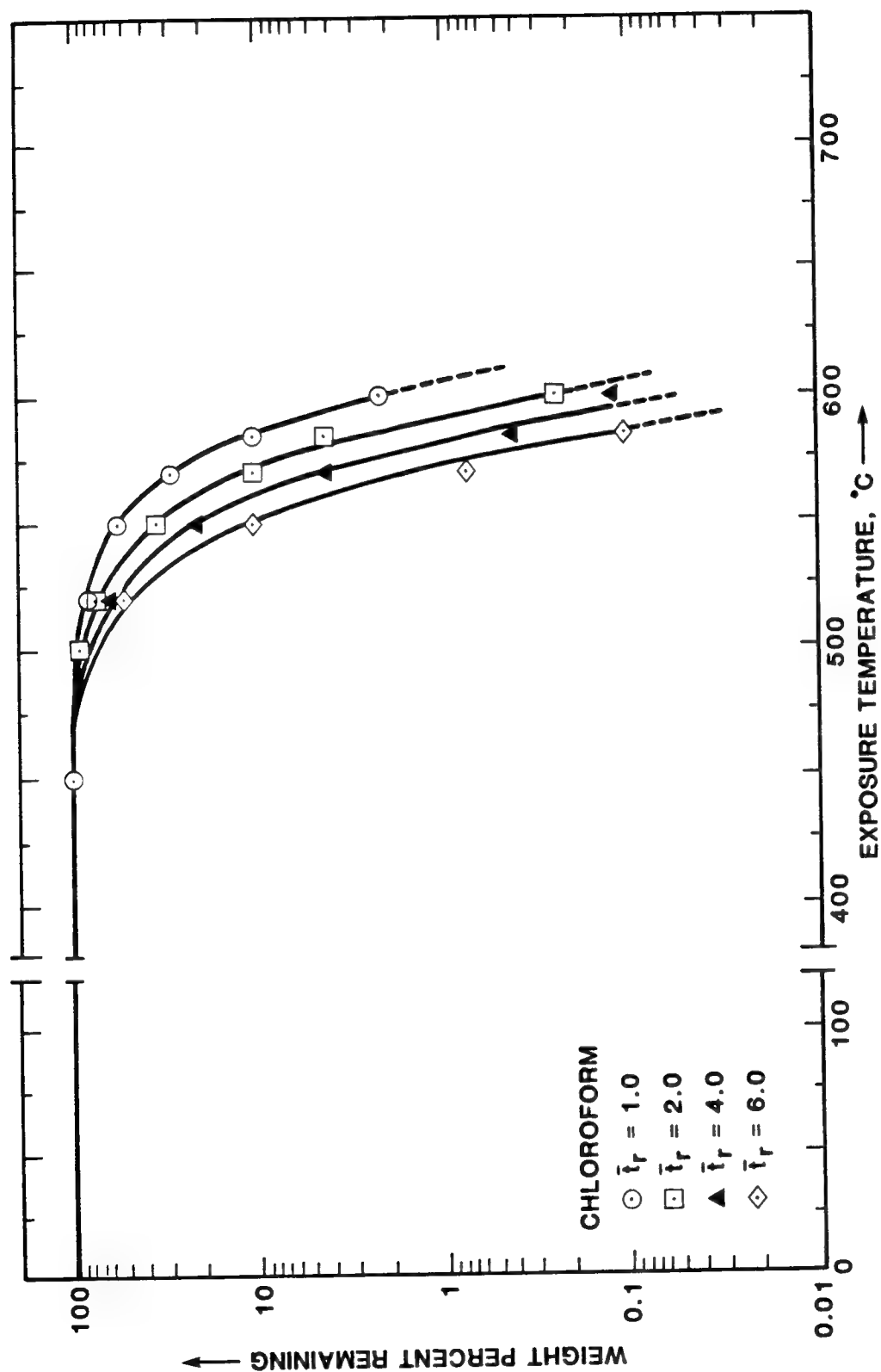
FIGURE A-2

THERMAL DECOMPOSITION PROFILES FOR CHLOROFORM IN FLOWING AIR AT MEAN RESIDENCE TIMES OF 1.0, 2.0, 4.0, AND 6.0 SECONDS

A-7

TABLE A-1
THERMAL DECOMPOSITION DATA FOR CHLOROFORM

Mean Residence	Exposure Temperature - T($^\circ$C)						
Time r (seconds)	400	500	520	550	570	585	600
1.0	100		81.2	55.7	29.3	11.2	2.29
2.0	100	86.0	74.4	34.8	10.3	4.29	0.24
4.0	100		58.5	21.3	4.27	0.41	0.13
6.0	100		51.0	10.4	0.75	0.108	>0.03

Source: Dellinger et al. 1984.

TABLE A-2

SUMMARY OF THERMAL DECOMPOSITION DATA

Compound	Empirical Formula	T_{onset} [1] (°C)	T_{99} [2] (°C)	$T_{99.99}$ [3] (°C)
Acetonitrile	C_2H_3N	760	900	950
Tetrachloroethylene	C_2Cl_4	660	850	920
Acrylonitrile	C_3H_3N	650	830	860
Methane	CH_4	660	830	870
Hexachlorobenzene	C_6Cl_6	650	820	880
1,2,3,4-Tetrachlorobenzene	$C_6H_2Cl_4$	660	800	850
Pyridine	C_5H_5N	620	770	840
Dichloromethane	CH_2Cl_2	650	770	780
Carbon Tetrachloride	CCl_4	600	750	820
Hexachlorobutadiene	C_4Cl_5	620	750	780
1,2,4-Trichlorobenzene	$C_6H_3Cl_3$	640	750	790
1,2-Dichlorobenzene	$C_6H_4Cl_2$	630	740	780
Ethane	C_2H_6	500	735	785
Benzene	C_6H_6	630	730	760
Aniline	C_6H_7N	620	730	750
Monochlorobenzene	C_6H_5Cl	540	710	780
Nitrobenzene	$C_6H_5NO_2$	570	670	700
Hexachloroethane	C_2Cl_6	470	600	640
Chloroform	$CHCl_3$	410	590	620
1,1,1-Trichloroethane	$C_2H_3Cl_3$	390	570	600

Source: Dellinger et al. 1984.

[1] The temperature at which thermal decomposition begins with a residence time of 2 seconds.

[2] The temperature at which 99 percent of the compound is thermally decomposed with a residence time of 2 seconds.

[3] The temperature at which 99.99 percent of the compound is thermally decomposed with a residence time of 2 seconds.

[1984] study). With respect to Table A-2, it is useful to note that a 40°C rise in temperature increases the DRE of methane, in the residence time of 2 seconds, from 99 percent to 99.99 percent.

COMBUSTOR SELECTION CONSEQUENCES

The mechanisms and kinetics described above lead to certain specific conclusions concerning achieving 99.99 percent DRE for the hazardous waste in a full-scale incineration system. These conclusions relate to creating the type of incineration environment or regime necessary to achieve the desired level of hazardous waste control. Essentially, the conclusions reinforce the "3Ts" of combustion: time, temperature, and turbulence (turbulence is necessary to achieve intimate contact between contaminants and oxygen, and the consequent thermal oxidation without significant hazardous waste breakthrough). In summary, the conclusions are as follows:

1) All hazardous compounds burn in the gas phase. Consequently, the incineration system accepts the wastes in various forms and brings them to a gaseous state by pyrolysis, melting and boiling, or sublimation. The goal of the primary reactor is then to raise the temperature of the soils to at least 900°C, in order to provide a margin of safety above T_{onset} for the most stable reactant (see Table A-2). The 900°C temperature was chosen based on the need to pyrolyze and destroy the high molecular weight compounds, such as aldrin, where significant thermal stability exists. It is noted that organic contaminants, such as aldrin, endrin, dieldrin, and isodrin, that are present in Basin F waste have higher heat of combustion values than tetrachloroethene, the second most thermally stable compound in Table A-2 (Appendix VIII, 40 CFR 261). Therefore, preliminary selection of 900°C operating temperature for the primary chamber seems appropriate. It is also assumed that this temperature is to be sufficient to achieve 99.99 percent DRE when both the primary chamber and afterburner are used. Further, the incinerator holds the contaminated soils at 900°C for some

significant time (e.g., 30 minutes) in order to ensure that all of the waste is brought to a condition where incineration is achievable.

2) Since all hazardous compounds burn in the gas phase, an after-burner is necessary regardless of the type of primary incinerator employed. For a fluidized bed incinerator, this afterburner is a large freeboard space, capable of a residence time of 2 seconds. Any system without an afterburner of some type has a significantly lower probability of success.

3) Of the interrelated factors (3Ts) of combustion, temperature is probably the most critical. Time is of less importance in achieving 99.99 percent DRE. Turbulence is ensured by combustion system design. Because temperature is probably most critical, the preferred reactor must be capable of achieving high temperatures both in the primary incinerator and in the afterburner. Further, the primary incinerator must have highly desirable heat transfer characteristics from the heat source (e.g., fossil fuel flame) to the contaminated soils. Without highly effective heat transfer mechanisms, the high temperatures achieved will be less than optimally employed.

4) The regime identified above is based on a review of combustion theory without benefit of empirical data. It is to be refined and modified based on further laboratory testing.

Appendix B
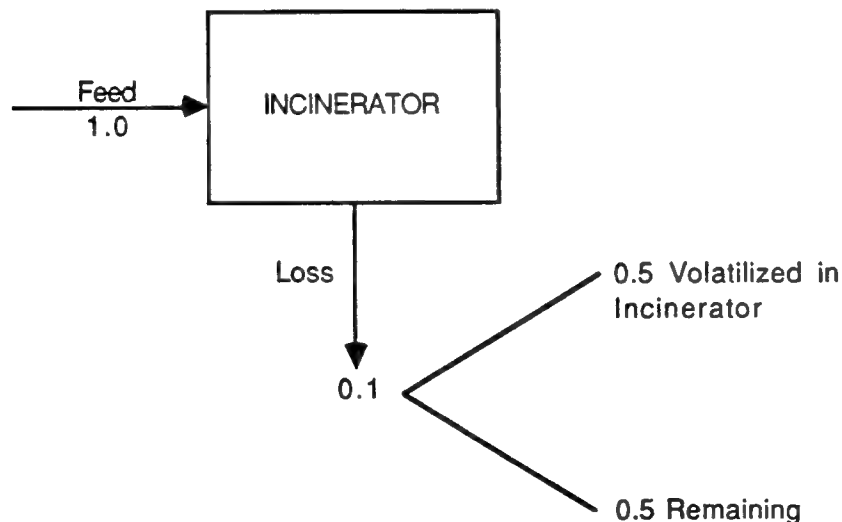
Premature Soil Loss Calculations

APPENDIX B

PREMATURE SOLIDS LOSS CALCULATIONS

As previously discussed in Chapter 3.0, in order to achieve a 99.99 percent destruction and removal efficiency (DRE), the premature solids loss must be held below 1 percent, assuming that 99 percent of the organic contaminants volatilize before the premature solids loss exit the incinerator. DRE efficiencies are calculated in Chapter 3.0 as a function of the percent volatilization before premature soils loss and as a function of the percent premature solids loss. Calculations were made for 50, 90, 99, and 99.9 percent volatilization of premature soil loss and for 10, 7, 5, 3, and 1 percent premature solids loss. Again, 100 percent volatilization of the remaining soil in the incinerator was assumed. Example calculations are provided below.

CASE 1

    50 percent Volatilization Before Premature Solids Loss (0.5)
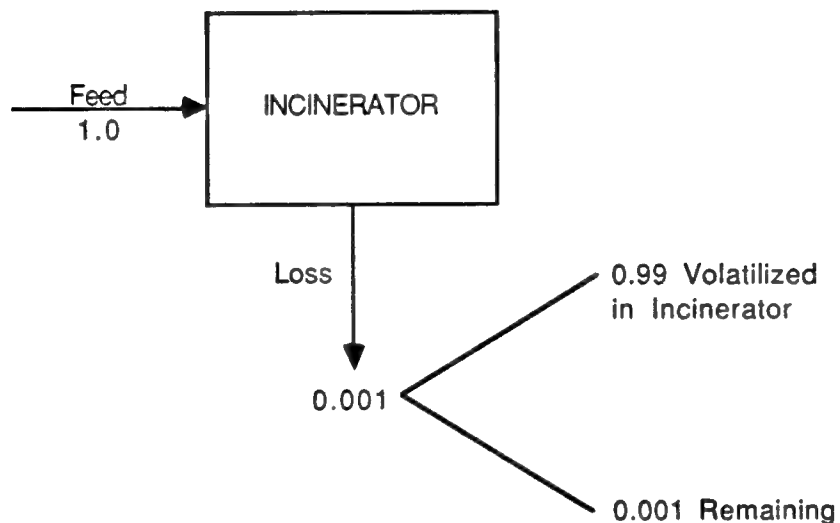   10 percent Premature Soil Loss (0.10)

    then (0.1) (0.5) = 0.05
        (1-0.05)(100) = 95% DRE
1319D   06/21/88

B-1

CASE 2

Represents Minimum Condition for a 99.99 percent DRE
99 percent Volatilization Before Premature Solids Loss (0.99)
1 percent Premature Soil Loss (0.01)

```
                    ┌──────────────────┐
      Feed          │                  │
  ─────────────────▶│   INCINERATOR    │
      1.0           │                  │
                    └──────────────────┘
                             │
                        Loss │                  ╱ 0.99 Volatilized
                             │                ╱   in  Incinerator
                             ▼              ╱
                          0.001 ──────────◂
                                            ╲
                                              ╲
                                                ╲ 0.001 Remaining
```

then $(0.01)(0.01) = 0.0001$
      $(1-0.0001)(100) = 99.99\%$

As previously discussed, Case 2 represents the minimum conditions in order
to achieve a 99.99 percent DRE. The calculation indicates that no more than
1 percent premature solids loss can be tolerated assuming 99 percent
volatilization before premature solids loss.

Appendix C

Response to EPA Region VIII Comments
Technology Selection Report

APPENDIX C

RESPONSE TO
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII COMMENT

A copy of the original letter of the EPA Region VIII comments is on file at PMO.

Only comments applicable to the report titled "SELECTION OF INCINERATION TECHNOLOGY FOR BASIN F WASTES AT ROCKY MOUNTAIN ARSENAL," dated September 1986 are discussed here. In the EPA letter these comments are presented under the heading B. SCREENING OF ALTERNATIVES.

COMMENT NO. 1

Dropping the circulating fluid bed (CFB), the infrared furnace and the whole class of "low temperature thermal" processes does not seem reasonable at this early stage. There is considerable data on the CFB with soils to include PCB certification. There is data on the IR furnace with soils burning off PCBs, dioxins and other materials. Frankly, the mix of pollutants in the Basin F waste are not unusually difficult to burn or thermally desorb. We suggest that processes should be considered which involve thermal desorbtion of the contaminants into a relatively small carrier gas stream followed by thermal incineration. This minimizes heavy metal vaporization and refractory problems, reduces the gas velocities (reducing particulate carryover) and gas volume (reducing air pollution control requirements), and to some extent, reduces fuel consumption.

RESPONSE TO COMMENT NO. 1

The circulating fluidized bed (CFB) technology is specifically discussed in Chapter 4.0. Such a system is available, as a mobile unit, from Ogden Environmental Services for soil remediation. The reasons for not including the CFB are discussed during the ranking of the technologies. The infrared technology (i.e., Shirco) is not included since it requires extensive size

reduction of the feed material, it is not capable of efficiently handling sludges without the use of absorbents, it cannot handle liquid wastes, and the systems to date have not achieved air emissions that would satisfy many local municipalities. The results of the study conclude that the rotary kiln is the safest technology to use with regard to risk of failure. However, the selection of the rotary kiln technology does not in any way rule out the future piloting of the CFB reactor or the infrared technologies. Low temperature volatilization is evaluated in the Full-Scale Conceptual Design Report (Ebasco 1988).

Appendix D

Reponse to Shell Oil Comments
Dated January 9, 1987

RESPONSES TO SHELL OIL COMPANY COMMENTS

A copy of the original letter of the Shell Oil Company comments is on file at PMO.

RESPONSES TO LETTER COMMENTS

INTRODUCTORY PARAGRAPH COMMENT

We have reviewed the draft report on Selection of Incineration Technology for Basin F (Task 17). The existing technical record thus far does not support the selection or even the intensive study of incineration technology for Basin F or other materials. We believe the law requires the examination of alternative technologies and the circumstances of the Arsenal warrant such examination. We can, however, find no basis in the documentation, facts, or analyses available to us which require or justify the intensive effort devoted to incineration. We ask that Shell be provided the bases and rationale upon which the selection of incineration is predicated. If no adequate bases have been developed, then the activity represented by Task 17 does not comply with CERCLA (SARA) and the National Contingency Plan.

RESPONSE TO INTRODUCTORY PARAGRAPH COMMENT

Through the Task 28 Feasibility Study, the Program Manager's Office (PMO) for Rocky Mountain Arsenal Contamination Cleanup is evaluating various treatment and disposal alternatives for implementation of remedial measures at Rocky Mountain Arsenal. That particular process does comply with Comprehensive Environmental Response Compensation and Liability Act (CERCLA), Superfund Amendments Reauthorization Act (SARA), and the National Contingency Plan.

However, the PMO has considered an accelerated cleanup of Basin F. As a result, the PMO is gathering information on the technical and economic aspects or viability of incineration/thermal treatment (incineration) of Basin F wastes as the initial step towards development of a broad remedial action alternative for Basin F.

The broad objectives of Task Order 17 are summarized below. For a more detailed discussion, see Ebasco's April 1987 final (white cover) report titled "Final Technical Plan" (Technical Plan).

1. Recommend a preferred method for incineration/thermal treatment of Basin F wastes by conducting a literature review of incineration technologies. The results of this analysis are presented in the subject final (white cover) report prepared by Ebasco, September 1988, titled "Selection of Incineration Technology for Basin F Wastes at Rocky Mountain Arsenal" (Technology Selection Report).

2. Perform laboratory bench-scale experiments to establish the incinerability of the Basin F wastes. Ebasco has prepared a final report titled "Laboratory Test Plan for Incineration of Basin F Wastes at Rocky Mountain Arsenal," April 1987. A final (white cover) report on laboratory results was developed titled "Bench-Scale Laboratory Incineration of Basin F Wastes at Rocky Mountain Arsenal" (Basin F Laboratory Report), September 1988.

3. Conduct a pilot plant study to determine the advantages and disadvantages of various pilot plant alternatives, which include the following: no pilot plant, using an existing on-site pilot plant, a mobile or permanent on-site pilot plant, or an off-site pilot plant. A final (white cover) report was prepared by Ebasco titled "Analysis of Pilot Plant Alternatives for the Incineration of Basin F Wastes at Rocky Mountain Arsenal" (Pilot Plant Report), September 1988.

4. Prepare a conceptual design for an incineration/thermal treatment facility which will include capital and operating and maintenance costs; conceptual level plot plan, flow diagram, general arrangement, and elevation; equipment list; single page specifications; as well as discussing design concerns and alternative equipment configurations. The final (white cover) report is titled "Full-Scale Incineration Conceptual Design for Basin F Wastes at Rocky Mountain Arsenal" (Full-Scale Conceptual Design Report), September 1988.

5. As part of an Expansion Program, the bench-scale laboratory program
    was expanded to evaluate Section 36 wastes. This research includes
    organic and metal volatilization studies, characterization of Basin F
    liquid, determinations of the toxicity of the thermally treated
    residue, and additional bench-scale incineration runs. The draft
    brown cover report was issued in March 1988 and is titled
    "Bench-Scale Laboratory Incineration of Section 36 Wastes (Expansion
    Program) at Rocky Mountain Arsenal" (Section 36 Laboratory Report).
    The final (white cover) report is dated September 1988.

As a result, the purpose of the subject report is to identify the most
appropriate incineration/thermal treatment method currently available for
Basin F wastes by conducting a literature review.

COMMENT NO. 1

The premise that the incineration process should handle liquids and solids
concurrently may be flawed. This appears to preclude consideration of other
technologies that may be more suitable and economic for either liquid or solid
materials.

RESPONSE TO COMMENT NO. 1

The thermal treatment of the liquids and solids in a single incinerator was
selected because of the high solids-to-liquid ratio. Refractory concerns and
other incineration technologies for the liquid are discussed in the Full-Scale
Conceptual Design Report. Nonincineration technologies were not considered
since Task 17 is limited to incineration. Laboratory and pilot plant
experience is recommended to select the final method of thermal treatment of
Basin F liquids.

COMMENT NO. 2

Consideration should be given for treatment of Basin F liquid in an
incinerator of proven technology for handling alkali-containing wastes, e.g.,
submerged quench combustion systems designed by T-Thermal and Nittetu.

RESPONSE TO COMMENT NO. 2

The applicability of the submerged quench, or other appropriate reactors is discussed in the Full-Scale Conceptual Design Report.

COMMENT NO. 3

Consideration of the impact of the high levels of inorganic salts on rotary kiln and afterburner operation is technically deficient and may not be understood by the authors. Further consideration should be given to the effect of sodium ion on refractory, deposition of salts in equipment, and the overall impact on reliability, capacity, and maintenance.

RESPONSE TO COMMENT NO. 3

The impact of high levels of salts is independent of the selection of a rotary kiln afterburner, fluidized bed, or hearth reactor. As such, it is not discussed in the Technology Selection Report. It is recommended that actual concerns be addressed during pilot plant tests.

COMMENT NO. 4

In considering the incineration alternative for treatment of Basin F soils, consideration should be given to testing low temperature (600°F to 1,000°F) thermal desorption followed by a high temperature afterburner.

RESPONSE TO COMMENT NO. 4

The 1,650°F primary reactor temperature represents a conservative value. The degree of volatilization as a function of temperature and solids residence time is evaluated in the Section 36 Laboratory Report.

COMMENT NO. 5

Rotary kiln incinerators cannot be scaled up indefinitely in size. They may have the potential to burn large volumes of hazardous wastes, but it is not demonstrated technology with respect to dedicated treatment of contaminated soils.

RESPONSE TO COMMENT NO. 5

Rotary kilns of the size range anticipated for Basin F wastes are currently available from vendors. Rotary kiln is a demonstrated technology for the destruction of organic contaminants including those in a soil matrix.

COMMENT NO. 6

It is not clear from this literature study and the conclusion reached by the authors where the technical program will proceed from this point. Are laboratory and pilot testing planned to advance the selected technology and evaluate the unique problems that incineration of Basin F materials raise? We would like to be involved in the early stages of any such planning.

RESPONSE TO COMMENT NO. 6

Please refer to the response to the introductory paragraph.

RESPONSES TO SPECIFIC COMMENTS

COMMENT NO. 1

<u>Page v.</u> The report deals with the selection of incineration technology for Basin F through <u>literature review.</u> Most of the reservations or criticisms we have concerning this report stem from the fact that the technology is being selected on the basis of a literature review, and one is left with the impression that the author(s) have no first hand experience of the technology of incineration in general. Why is only a literature review being done for such a potentially important technology? A literature review can lead to poor decisions.

RESPONSE TO COMMENT NO. 1

The identification of incineration technology through a literature review, by authors experienced in the fields of incineration and combustion, is the initial step towards developing the recommendation of a preferred technology for thermal treatment of Basin F wastes. This is discussed in the Technical Plan. It is not suggested that incineration is the only solution or that the selection of incineration technology through a literature search is the only way to make such choices.

The PMO is well aware of caveats of selecting an incineration technology solely based on a literature search. For that particular reason, under the direction of the PMO and as mentioned in the Technical Plan, Ebasco has undertaken a laboratory program to determine the incinerability characteristics of Basin F and Section 36 wastes. Ebasco also recommends a pilot program to determine the operational and design characteristics of a preferred incineration technology.

COMMENT NO. 2A

Page vi. A basic assumption is to incinerate both liquids and solids in the
same incinerator. No basis for this very fundamental decision is
presented. Alternate technology might be available to economically treat
either liquids or solids.

RESPONSE TO COMMENT NO. 2A

Incineration of both the solids and liquids was selected because of the
expected high solids-to-liquid ratio. Incineration of the liquids in a
separate incinerator is discussed in the Full-Scale Conceptual Design
Report. Alternative technologies and economic considerations are being
evaluated under Task 28.

COMMENT NO. 2B

Three technologies are cited that are capable of incinerating commercially
both solids and liquids. In a very broad sense this is correct but all
three technologies have limited tolerance or ability to handle
satisfactorily wastes with high salt levels such as Basin F liquids. Proven
technology for the latter does not include admixture with soils.

Later in this section we have the first mention of a primary reactor and a
minimum temperature to vaporize most stable reactants. However, concerns
for salt melting are not addressed. Nevertheless, reference to a primary
reactor starts to establish the concept for an unnecessarily high
temperature for this first stage.

RESPONSE TO COMMENT NO. 2B

High salt levels in Basin F liquid may be a problem in the incineration
process, particularly in a fluidized bed reactor. Salt melting at higher
incineration temperatures precludes admixturing of Basin F liquid and
contaminated soils. Salt melting is recognized as a potential concern.

However, the admixture of liquids with solids and the incineration of the liquids in a separate incinerator are concerns that are addressed in the Full-Scale Conceptual Design Report. This will also be addressed during any pilot plant investigations performed prior to an implementation of a selected technology for Basin F wastes. These types of concerns cannot be resolved at the technology selection level and exist for all the technologies applicable to Basin F wastes: rotary kiln, fluidized bed, and hearth-type incinerators.

COMMENT NO. 3

Page vii. In discussing freeboard residence time there will be the need to consider the burning of NH_3.

RESPONSE TO COMMENT NO. 3

The effects of burning ammonia and urea do not affect the selection of technologies. The effects of ammonia and urea salts are discussed in the Full-Scale Conceptual Design Report.

COMMENT NO. 4A

Page viii. We have serious reservations about just how the screening selection is conducted, i.e., weighting of opinions of individuals conducting the selection. The maintenance and environmental factors are very low and may be difficult to justify if a more objective analysis is required in the future.

RESPONSE TO COMMENT NO. 4A

The method of screening was selected to evaluate which incineration/ thermal treatment method is most appropriate for further consideration, based on the literature review. The objective of such a process is to determine the technology that should be evaluated further through laboratory study and pilot program for consideration as one of the effective remedial measures.

The document "Guidance on Feasibility Studies Under CERCLA" (EPA/540/6-85/003, June 1985) provides for using acceptable engineering practice and the judgment of individuals.

Maintenance and environmental concerns, although important criteria in discriminating technologies, are not as critical in the selection process as the design and operating criteria, since these criteria directly affect the ability of the technology to achieve a 99.99 percent DRE.

Environmental and operating and maintenance concerns are discussed in Sections 3.5 and 3.6 of the subject report. Subsequent analyses and reports address specific design factors, emissions, operating and maintenance concerns, and costs.

COMMENT NO. 4B

Fluid bed technology is given a lower rating because of premature loss of solids. More importantly would be problems expected because of salts melting and consequent loss of fluidization of the bed.

RESPONSE TO COMMENT NO. 4B

Loss of bed fluidization (as indicated by Shell Oil), premature solids loss, retention time, and the need for a sized material were major reasons why the fluidized bed technology was not selected. Specific concerns with regard to salt melting are discussed in Sections 4.3.1 and 4.3.2 of the subject report.

COMMENT NO. 4C

The authors discuss a complete system for Basin F but do not address how or where a liquid would be fed. They mention the possibility of the kiln being used primarily to vaporize the hazardous organics. However, the temperature indicated, at least 1650°F, may be excessive for volatilization of the organic molecules from soils. We believe consideration should be given to testing low temperature (600-1000°F) thermal desorption followed by a high temperature afterburner.

4439D

06/21/88

D-9

RESPONSE TO COMMENT NO. 4C

The complete system is discussed in considerably more detail in the
Full-Scale Conceptual Design Report.

The use of 1,650°F in the primary reactor (kiln) may be excessive and
represents a conservative case. Bench-scale laboratory experiments were
conducted to demonstrate the thermal desorption of the contaminants from the
soil matrix as a function of temperature and residence time. These results
are presented in the Section 36 Laboratory Report. The pilot plant program
will also help in identifying optimum temperatures in the primary reactor.

COMMENT NO. 4D

We would agree that rotary kilns do lend themselves to larger scale-up than
some of the others cited. However it should be emphasized that because you
can have large cement or ore roasting kilns doesn't imply that you can do
the same with hazardous wastes. The maximum sizes for proven hazardous
wastes systems have been addressed in previous reports.

RESPONSE TO COMMENT NO. 4D

We agree that a large rotary kiln facility like that proposed for Basin F
has not been built to date. However, the kiln sizes selected are well
within the limits of currently available equipment and currently operating
systems including IT Corporation's mobile system.

As discussed in the Technical Plan, the subject report is the first phase in
the analysis of an incineration/thermal treatment option. These phases are
all ongoing. Kiln sizing is discussed in the Full-Scale Conceptual Design
Report. The pilot plant program will be used to ultimately size the kilns
in conjunction with results from the current laboratory program.

COMMENT NO. 5

Introduction Section Page 1-1. Here emphasis is made that they are making technology selection for further analysis. When will this be done? There are no screening designs and, as a result, the size of incinerators being considered is vague and limitations are not identified.

RESPONSE TO COMMENT NO. 5

This report is the first phase in the analysis of an incineration/ thermal treatment option. As indicated in response to the letter comments, the other phases of this program include Basin F and Section 36 laboratory investigations, pilot plant alternative evaluation, and a conceptual design of a full-scale system.

The size of the incinerator as presented in this report is based on an estimated waste volume of 418,000 cubic yards, a treatment time of 2.5 years, and an availability of 80 percent (7,000 hrs/yr of operation).

COMMENT NO. 6

Page 1-3. Here and elsewhere discussion is deficient from our viewpoint as they are still using earlier analyses and the presence of salts, i.e., the cations are only implied. We would like to see the presence of alkalis clearly stated and the potential problems this might cause addressed (in addition to the brief comment at the top of page 1-5).

RESPONSE TO COMMENT NO. 6

Specific problems caused by the presence of alkalis are discussed in the Full-Scale Conceptual Design Report. This discussion includes refractory concerns and incineration of the Basin F liquid in a separate incinerator. At the technology selection level, it is sufficient to know that appropriate refractories are available and that commercial systems are available for thermal treatment of liquids similar to those of Basin F.

COMMENT NO. 7

Table 1.2-1 has a corrosivity number which appears incorrect. Probably a misprint for mils (1 mil = 0.001 inch). Even so the value is questionably too high. This identical number was also shown on the vu-graphs presented by A.D. Little to the Feasibility Study Committee.

RESPONSE TO COMMENT NO. 7

Corrosivity numbers presented in Table 1.2-1 are incorrect. The correct numbers are 50 mm per year for Basin F liquid and 1.1 mm per year for the soil. EPA Method 1110 was used for determining corrosivity and that method specifies the corrosivity unit in millimeters per year.

COMMENT NO. 8

Table 1.2-2. Footnote 3 is incorrect due to ppb values also being reported in the table. Also, the data reported in the table demonstrate the variability of the composition of the Basin F materials. It is possible that the variability might be critical in any design prepared and needs to be better defined.

RESPONSE TO COMMENT NO. 8

Footnote 3 in Table 1.2-2 should read "Values in percent can be calculated by dividing the ppm table values by a factor of 10,000." This correction has been incorporated into the report.

The variability of the concentration of contaminants in Basin F is well established as a function of location for both solids and liquids. Variability at Basin F is expected, particularly in areas of liner failure. Variability will be addressed during test burns in the pilot plant program and is outside the scope of this program.

COMMENT NO. 9

Page 1-4. The last paragraph makes a statement that the Basin F problem is more one of materials handling rather than one of hazardous waste incineration. This type of thinking leads directly to major problems such as scaling up on basis of cement kiln experience and not appreciating subtleties of handling alkali brines in a proven manner.

RESPONSE TO COMMENT NO. 9

The subject sentence was referring to the difficulties involved in handling the Basin F wastes during excavation, while feeding to the kilns, and in passing through the kilns. Because of the sentence's ambiguous nature, it has been removed.

COMMENT NO. 10

Section 2.0. Incineration Technology Overview. Anything "under development" should be discounted if timetables are to be adhered to. Summary of total units in service appears to consider domestic units only, whereas it is clearly recognized in EPA literature, and elsewhere, that European technology and in particular their solid waste incineration technology is extensive.

RESPONSE TO COMMENT NO. 10

Technologies under development were only included for completeness. It is agreed that these technologies, even if they have some desirable features, are not appropriate to RMA because of the timeframe involved.

It is agreed that Europeans have significant experience in hazardous waste incinerators. European experience confirms the use of rotary kilns.

COMMENT NO. 11

Page 2-3. Discussing Fluid Bed Limitations. Inorganic materials are only good to have present if they are refractory in nature; otherwise the inorganics in the feed are the primary cause of bed fluidization problems because of melting of salts alone or as eutectic mixtures. Interaction between bed material and feed to produce lower softening material is next in concern.

RESPONSE TO COMMENT NO. 11

We agree with the above comment. Please refer to Section 2.3 of the subject report.

COMMENT NO 12

Section 2.4. Hearth Types. This section is confusing because no clear distinction is made between fixed hearths and rotary, single or multiple hearths. Rotary hearths were previously used primarily for ore roasting, but in recent years they have been widely used for thermal treatment of biosludges. The statement that multiple hearths are not suited for wastes with high inorganics needs to be clarified, since all ores are primarily inorganic. Rather the statement should say that feeds with inorganics that melt (particularly complex salt mixtures) should be avoided. Again a statement is made that there are 16 domestic manufacturers of hearth type incinerators. Of these manufacturers, only two produce rotary multiple hearths and most have little creditable track records in designing or handling hazardous wastes. Why this type of statistical data (?) is introduced is not clear.

RESPONSE TO COMMENT NO. 12

Multiple hearths with rotating rabble arms are discussed because this configuration is more appropriate than the other types to the contaminants in Basin F. These units provide mixing of the material to improve heat

transfer, drying and combustion zones are easily operated at different conditions, and this type of configuration is typical of high solid sludges and cake materials.

The comment that multiple hearths are not suited to material with high contents of inorganic compounds was intended to refer to complex salt mixtures. This has been clarified in the text.

The statement regarding manufacturers and the number of hearth-type incinerators was made merely to show that the technology is readily available.

COMMENT NO. 13

Section 2.5 Pyrolysis Reactors. This section has several minor inconsistencies in defining pyrolysis as thermal decomposition with no mention of the additional benefit of volatilization. The concern with this section lies with the ambiguity of the second paragraph discussing the nonacceptability of materials containing N,S,Si,P, etc. The intent of the statements is unclear to us. There is no apparent reason why a "pyrolysis reactor" could not be followed by an afterburner and other equipment.

RESPONSE TO COMMENT NO. 13

There is no technical reason why a pyrolysis reactor cannot be coupled to an afterburner and downstream air pollution control equipment.

However, single or multiple units in the size range required are not commercially available. For example, the PyroBatch System has a capacity of 30,000 lb (15 tons) but the residence time is 4 to 6 hours, which calculates to a continuous feed rate of only 2.5 to 3.75 tons/hour. Further, pyrolysis units are typically custom designed to process specific types of wastes rather than as multipurpose waste processing units. This is a significant concern with regard to the variability detected in the Basin F materials and site variability if other materials are to be incinerated.

The sentence discussing the nonacceptability of materials containing N, S, Si, Pi, etc., was ambiguous and has been removed.

COMMENT NO. 14A

Sections 2.6-2.10. The general review of other technologies is reasonably consistent and we would have only minor concerns, i.e., talks about sodium carbonate being fluidized when it should refer to the carbonate being molten!

RESPONSE TO COMMENT NO. 14A

The term fluidized was improperly used. Sodium carbonate melts at approximately 1,560°F (850°C). As a result, the sodium carbonate salt in a molten salt incinerator is molten. The sentence in the report has been corrected.

COMMENT NO. 14B

Their general comments and conclusion regarding the limitations of the various processes are in line with our thoughts, except we would be even less enthusiastic about most of them either now or in the future. Discussing the Advanced Electric Reactor and abilities to handle large volumes of soils, there is obviously a difference of opinion regarding what is meant by large volumes of soils as trials to date with this technology have never been with more than a few hundred pounds of soils.

RESPONSE TO COMMENT NO. 14B

The Advanced Electric Reactor was addressed for completeness. "Large volume of soils" refers specifically to laboratory and small pilot-scale devices. These devices, at present, are not capable of handling the large quantities of Basin F waste.

COMMENT NO. 15

Section 2.13. Conclusion. They should note that kilns have a _potential_ to treat large volumes of soils, but it is _not_ demonstrated technology with respect to soils.

RESPONSE TO COMMENT NO. 15

Kilns are a proven technology for handling large volumes of solid materials including cement, aggregate, minerals, etc. It is agreed that facilities (but not individual kilns) have not been built for soils incineration that are of the size required to handle Basin F wastes. Historically, there has been little incentive to thermally treat soils. Only recently, with the new hazardous waste regulations, has this been a concern. Kiln systems are available to treat soils, including equipment offered by John Zink; Rollins; Roy Weston; Ensco; IT Corporation; EPA's Mobile Incinerator; Vesta; M&S Engineering and Manufacturing; International Waste Energy Systems, Inc; and others. The key concerns in the successful handling of soils in rotary kilns is the identification of waste characteristics. The laboratory analyses conducted under this program will be coupled with a well-designed pilot plant program. From this information, kiln design parameters will be confidently set.

COMMENT NO. 16

Page 3-1. They talk about a conservative temperature of 900°C to ensure complete volatilization from soils, yet there is no data to support this statement. The "additional discussion" in Appendix A does not address this.

The work of Dellinger is cited to defend certain choices of temperature or residence time; but without considerable explanation, the data has little applicability. There is also talk about residence time in the flame as if this is the most critical factor rather than residence time at a given temperature. Most of the other objections to statements in this section have been commented on earlier.

RESPONSE TO COMMENT NO. 16

Although it is not clear in the text, the work of Dellinger was included for
the afterburner conditions only. This has been clarified in the text. As
previously indicated, the use of 1,650°F in the primary reactor (kiln) may
be excessive and this represents a conservative case. Experiments in the
Section 36 Laboratory Report were conducted to demonstrate the thermal
desorption of the contaminants from the soil matrix as a function of
temperature and solids residence time.

COMMENT NO. 17

Page 3.3, paragraph 1. The criteria that are listed in this paragraph are
not all of equal importance. The assumption that all of these excluded
criteria are of equal importance regardless of the technology may be a fatal
flaw in the analyses being performed.

RESPONSE TO COMMENT NO. 17

In order to stay within the constraints of the study, all criteria in
Table 3.2-1 were not considered. Criteria that were judged equal between
all technologies were not applied to each incinerator/thermal treatment
option. At the level of this study, only factors that directly affect the
unit's ability to achieve the required DRE, operate safely, minimize
emissions, minimize maintenance, and minimize costs were considered (as
summarized in Table 3.2-2). The weighing factors in Figure 3.8-1 were
applied to those criteria. As indicated, the most critical factor is the
ability of the device to achieve the specific design/operation criteria
listed below:

1. Reaction temperature
2. Residence times
3. Design capacities
4. Capability of handling feedstocks of varying compositions
5. Minimize solids loss.

If the device cannot achieve these criteria, it is simply not capable of handling Basin F material within the constraints of the study and is not worth further evaluation.

COMMENT NO. 18

Page 3-5, paragraph 1. In the first line they state that liquids may or may not be mixed with solids. This statement is a generality that could lead to major problems, especially with Basin F liquid. If the solid to liquid ratio were much larger than the 20:1 ratio of solids to liquids tabulated earlier in the report, it might be a feasible approach to dribble in the salty liquid.

RESPONSE TO COMMENT NO. 18

If incineration is selected as the technology for Basin F wastes, then a pilot study will be performed prior to implementing such technology. One of the main objectives of the pilot operation will be the evaluation of the effect on the incinerator due to mixing of liquid and soil for cofiring in the incinerator. That is why we have made a statement of this nature. Incineration of Basin F liquids is discussed in more detail in the Full-Scale Conceptual Design Report.

COMMENT NO. 19

Page 3-5, paragraph 2. What is the basis for stating that four reactors are required? How was the cost effectiveness of this determined? What criteria were utilized in the analyses?

RESPONSE TO COMMENT NO. 19

The number of reactors is based on thermal treatment of the soils in 2.5 years and conservative design factors. Subsequently, these design factors have been re-evaluated and the number of kilns reduced from four to two.

4439D

06/21/88

COMMENT NO. 20

Page 3-5, paragraph 3. An analyses of the impact of volatile metals would be appropriate considering the analytical results from Phase I.

Response to Comment No. 20

Major metals found at RMA that show evidence of high levels of partitioning include arsenic, cadmium, lead, mercury, zinc, and in some cases, copper. Metal partitioning was studied as part of the Section 36 Laboratory Report.

COMMENT NO. 21

Page 3-6. Volatilization Before Premature Soils Loss. This table raises many of our more general concerns about how clean is clean and can you determine DRE's of 99.99% at very low contaminant levels.

RESPONSE TO COMMENT NO. 21

The DRE of 99.99 percent for principal organic hazardous constituents (POHCs) is an EPA requirement for non-PCB incinerators and is not tied to how clean is clean. The DRE is simply a measure of the concentration of POHCs in the feed and in the stack gases. The concentrations of POHCs in the thermally treated residue and other solid residues do not enter into the calculation. This is a matter for a risk assessment.

COMMENT NO. 22

Page 3-7, paragraph 3.5. There would be a discussion on the impact of coal on the environmental considerations. Of particular concern is the particulate problem. Also, there should be an analyses of the inter-relationship between the maintenance difficulties of each technology and the environmental consequences of maintenance failures.

RESPONSE TO COMMENT NO. 22

The use of coal as a fuel has been deleted from the text. An analysis of the relationship between maintenance difficulties for each technology is outside the scope of this work effort.

COMMENT NO. 23

Page 3-8, paragraph 3.6. The extremely limited attention being accorded the maintenance considerations could be a fatal flaw in the analyses. As noted above in preceding paragraph, this needs to be examined in a much greater detail.

RESPONSE TO COMMENT NO. 23

Please refer to the Response to Comment No. 22.

COMMENT NO. 24

Page 4-1, Section 4.1. There is no evaluation that addresses the primary assertion that both liquids and solids need to be processed in the same facility. In addition, there is no evaluation of separate liquid and solids incineration versus the technologies evaluated let alone the alternate technologies. When is this to be done?

RESPONSE TO COMMENT NO. 24

The ultimate disposal of the Basin F liquid wastes is further discussed in the Full-Scale Conceptual Design Report.

COMMENT NO. 25

Page 4-1, Section 4.2. The statement that rotary kilns are fired by pulverized coal should have the provision that this is not so for hazardous waste units, as we have yet to find any which are doing this with coal.

RESPONSE TO COMMENT NO. 25

We agree that pulverized coal is not used for hazardous waste kilns. The text has been changed accordingly.

COMMENT NO. 26

Page 4-5, Section 4.2.2. Afterburner Design Considerations. Some very high levels of excess air are given (120-200 percent) which would be incredibly wasteful with a low heat of combustion waste. The values given on page 4-6 for excess air of 11 and 17 percent are more typical.

RESPONSE TO COMMENT NO. 26

It is agreed that high values of excess air of 120 to 200 percent, although sometimes used, are wasteful of energy. The values of excess air on page 4-6 refers to the fuel burner. The typical values of excess air for combustion of natural gas and fuel oil are 5 to 10 percent and 3 to 15 percent, respectively. However, the purpose of the incinerator device is to volatilize and destroy the contaminating organics while minimizing the generation of products of incomplete combustion (PICs). Work by Kramlich et al. (Laboratory Scale Flame Mode Hazardous Waste Thermal Destruction Research, 1984) indicates that optimum levels of excess air for achieving 99.99 percent DRE are 25 to 50 percent. Levels above and below this cause excessive production of carbon monoxide (CO) and other PICs with a corresponding decrease in the DRE.

COMMENT NO. 27A

Page 4-7, second paragraph. Here some comment is made about burning a high salt waste in an afterburner. Based on our own experience and that of proven alkali burning technology of others like T-Thermal and Nittetu, it may be undesirable to inject alkali brines into an afterburner operating at more than 1,800°F. It is our current opinion that the liquids and solids operations should be separate and not coupled in any way, unless it can be done without compromising the performance.

4439D

06/21/88

D-22

RESPONSE TO COMMENT NO. 27A

We agree that it may not be desirable to inject Basin F liquids into the afterburner and may or may not be appropriate to mix the liquids into the soil. Another option includes the use of an independent stand-alone incinerator for the liquid. These options are evaluated in the Full-Scale Conceptual Design Report. Pilot plant experience would be desirable in making this determination.

COMMENT NO. 27B

The afterburner exit gas velocity is stated to be 5,000 ft/minute (83 ft/second), which is far too high for a two-second residence time and a 4:1 height/diameter ratio.

RESPONSE TO COMMENT NO. 27B

Gas residence times in afterburners typically range from 0.2 to 6.0 seconds depending on the type of pollutant. A typical gas residence time is 2.0 seconds. Afterburners operate at high gas velocities in order to promote good mixing. Typical gas velocities range from 25 to 50 feet/second (1,500 to 3,000 feet/minute). Since exit duct diameters and/or reactor transitions are less than the cross-sectional area of the afterburner, exit duct velocities could easily exceed 5,000 feet/minute (83 feet/second).

COMMENT NO. 28

Page 4-8, second paragraph. A statement is made that little bound nitrogen is in the waste to be treated so the only source of NO_x would be fuel and air. On the basis of our current understanding of liquid composition this is not the case, e.g., urea ammonia salts and urea.

RESPONSE TO COMMENT NO. 28

Please see Response to Comment No. 3.

4439D   06/21/88

COMMENT NO. 29

Page 4-18, Section 4.7. These conclusions should be highly qualified as this report is only a literature survey and the tentative conclusions need to be verified by other means, including laboratory tests and expert judgment.

RESPONSE TO COMMENT NO. 29

This report was the initial phase in the evaluation of the incinerator/ thermal treatment option. The rotary kiln/afterburner option was selected on the basis of a literature review.

Appendix E

References

APPENDIX E

REFERENCES

Bonner, T., et al. 1981. Hazardous Waste Incineration Engineering. Noyes Data Corporation, Park Ridge, New Jersey.

Brunner, C.R. 1984. Incineration Systems--Selection and Design. Van Nostrand Reinhold Company, New York, 14.4.

Buhts, R.E., N.R. Francinques, and A. J. Green. 1979. Basin F Investigative Studies, Chemical Assessment and Survey. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. P. 1-2.

Dellinger, B., et al. 1984. Determination of the Thermal Decomposition Properties of 20 Selected Hazardous Organic Compounds. EPA-600/2-84-138. Prepared by the University of Dayton, Research Institute, Environmental Sciences Group, Dayton, Ohio, for the Environmental Protection Agency. 204 p.

Dikeou, J.T. 1980. Cement. P. 143-158. In: Bureau of Mines, Bulletin 671 (ed.). Mineral Facts and Problems. U.S. Government Printing Office, Washington, D.C.

Ebasco (Ebasco Services Incorporated). 1985. Closure Plan-Basin F, Rocky Mountain Arsenal. Prepared for U.S. Army Program Manager's Office for Arsenal Contamination Cleanup. 13 p.

Ebasco (Ebasco Services Incorporated). 1987. Final Technical Plan for Incineration/Fixation and Building 1611 Pilot Study for Basin F Wastes at Rocky Mountain Arsenal. Task No. 17. Prepared for U.S. Army Program Manager's Office for Rocky Mountain Arsenal Contamination Cleanup.

Ebasco (Ebasco Services Incorporated). 1988. Final Full-Scale Inciner-
ation System Conceptual Design for Basin F Wastes at Rocky Mountain
Arsenal. Prepared for U.S. Army Program Manager's Office for Rocky
Mountain Arsenal Contamination Cleanup.

Edwards, B.H., et al. 1983. Emerging Technologies for the Control of
Hazardous Wastes. Noyes Data Corporation, Park Ridge, New Jersey.

Frankel, I., N. Sanders, and G. Vogel. 1983. Survey of the Incinerator
Manufacturing Industry. Chemical Engineering Process 79(3):44-55.

Freeman, H.M., et al. 1985. Evaluation of Pilot-Scale Pollution Control
Devices for Hazardous Waste Incineration. EPA-600/D-85/204. Prepared
by the Environmental Protection Agency, Cincinnati, Ohio. 27 p.

Gin, W., et al. 1982. Technologies for the Treatment and Destruction of
Organic Wastes as Alternatives to Land Disposal. Prepared by the
Industrial Strategy Development Branch of the California Air Resources
Board. P. 64.

Keitz, E., et al. 1984. Profile of Existing Hazardous Waste Incineration
Facilities and Manufacturers in the United States (Final Report).
EPA/600-2-84-052. Prepared by Mitre Corporation, McLean, Virginia, for
the Environmental Protection Agency. 167 p.

Kiang, Y.H., and A.H. Metry. 1982. Hazardous Waste Processing Technology.
Ann Arbor Science, Ann Arbor, Michigan. 4 p.

REFERENCES (Continued)

Perry, R.H., and C.H. Chilton. 1984. Chemical Engineers' Handbook. McGraw-Hill Book Company, New York, New York.

Westinghouse. 1987. Presentation by Westinghouse at the Environmental Protection Agency, Region X office in Seattle, Washington. April 23, 1987.